Stochastic modelling of soil carbon stocks under different land uses: a case study in South Africa

by
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Declaration

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ABSTRACT

The research was conducted in the Kwa-Zulu Natal midlands, South Africa. The vertical distribution of soil organic carbon (SOC) stocks were successfully predicted by stochastic exponential models developed for the three main land uses in the area, which are farmlands, forestry plantations and grasslands. These models, in combination with regular surface sampling, may be used for monitoring SOC dynamics in the area and mapping SOC stocks.

Bulk density measurements are needed in combination with SOC content ($\%_{wt}$) to calculate such SOC stocks. Considering the disadvantages of bulk density sampling and measurement, an effort was made to determine if one of the commonly-used existing stochastic models could be used to successfully predict bulk densities for soils with known texture and SOC content to replace direct measurements, taking into account that different managements might affect final results. Statistica software was used to correlate the Saxton & Rawls model predictions and associated regressions with measured values for the study area. A clear distribution trend was achieved using Statistica and the correlations were fair with r^2 values close to 0.5 for individual regressions and substantially higher for area averages. However, considering the depth-stratified averages and correcting for the effects of particle density changes for soils with high soil organic matter, high correlations for 2 of the 3 studied land uses were achieved (r^2 values of 0.99 and 0.81 in forests and grasslands respectively). Therefore, although Saxton and Rawls (2006) predictions of bulk density may be used, it is preferable to conduct direct bulk density determinations.

The proposed models to calculate the vertical distribution of SOC would substantially reduce the cost of soil carbon inventories to 1m soil depth in the study area by limiting observations to the soil surface. Triplicate 5cm-deep soil core samples would be collected at the soil

surface per observation point for determination of ρ_b (bulk density) and C_{org} (organic carbon). On average, the accuracy of the normalized depth-distribution model is rather high for grasslands and forests/forest plantations ($R^2 = 0.98$), but somewhat lower for cultivated lands ($R^2 = 0.96$) due to mixing of the plough layer to cultivation depth.

Carbon stocks to 1m depth were calculated as an integral of the normalized exponential distribution, multiplied by the value of $_{Corg}$ observed at the soil surface and expressed on volume basis as carbon density (Cv, $kg \cdot m^{-3}$). The resulting stock assessment was compared to the observed values using piece-integration for sampled depth increments to give SOC stocks on an area basis ($kg \cdot m^{-2}$). The estimated prediction error on average was 1.2 (9%) and 3.7 $kg \cdot m^{-2}$ (21.6%) in grasslands and forests respectively, while for cultivated lands the error was 1.3 $kg.m^{-2}$ (9.5%). Further improvement to reduce these errors may be achieved by introducing the soil type as variable and grouping the functions by soil type rather than land uses.

The results of this work were presented at the seminar of the department of Soil Science, Stellenbosch University (Ros et al., 2014), the combined congress of the South African Soil Science, Horticulture and Agronomy societies (Rozanov et al., 2015), the First Global Soil Map conference, France (Wiese et al., 2013), the 20th International Congress of Soil Science, Korea (Wiese et al. 2014) and were submitted for publication in Geoderma special issue dedicated to digital soil mapping of soil organic carbon following the presentation at the 20th ICSS, Korea (Wiese et al., 2014).

UITTREKSEL

Hierdie navorsing is in die Kwa-Zulu Natalse middellande van Suid-Afrika gedoen. Die vertikale verspreiding van grondorganiese koolstof (GOK) is suksesvol voorspel deur middel van stogastiese eksponensiële modelle wat vir die drie hoof landsgebruike ontwikkel is. In kombinasie met roetine monsterneming by die grondoppervlak kan hierdie modelle suksesvol aangewend word vir die monitering van GOK dinamika in die studiegebied, sowel as kartering van GOK voorraad.

Bulkdigtheidsmetings word tesame met GOK inhoud ($\%_{massa}$) benodig om die GOK voorraad te bereken. Weens die nadele van monsterneming vir bulkdigtheidsbepalings is 'n poging aangewend om te bepaal of een van die mees algemeen gebruikte bestaande stogastiese modelle (Saxton & Rawls 2006) gebruik kan word om die bulkdigtheid van gronde suksesvol vanaf tekstuur en GOK inhoud te voorspel en sodoende direkte metings te vervang. Statistica sagteware is gebruik om die voorspellings met behulp van die Saxton & Rawls modelle en gevolglike regressies met gemete waardes vanuit die studiegebied te korreleer en 'n duidelike verspreidingstendens is hierdeur opgelewer. Die korrelasies vir individuele regressies was redelik met r^2 waardes naby 0.5 en merkwaardig hoër waardes vir area gemiddeldes. Hoë korrelasies is egter behaal vir 2 van die 3 bestudeerde landsgebruike (r^2 waardes van 0.99 en 0.81 in bosbou en grasveld onderskeidelik) wanneer die gemiddelde dieptestratifikasies gebruik en gekorrigeer word vir die verandering in deeltjiedigtheid vir gronde met hoë grondorganiese material. Alhoewel die Saxton and Rawls (2006) voorspellings van bulkdigtheid gebruik kan word, behoort bulkdigtheidsbepalings egter verkieslik direk gedoen te word.

Die voorgestelde modelle vir die bepaling van vertikale GOK verspreiding tot 1m gronddiepte sou die koste van grondkoolstof opnames in die studiegebied dramaties verlaag deur grondmetings tot die grondoppervlak te beperk. Grondmonsters sal in triplikaat per

waarnemingspunt met 5cm diep silinders op die grondoppervlak geneem word vir ρ_b (bulkdigtheid) and C_{org} (organiese koolstof) bepalings. Die gemiddelde akkuraatheid van die genormaliseerde diepteverspreidingsmodel is hoog vir grasveld en woude/bosbou plantasies ($R^2 = 0.98$), maar ietwat laer vir bewerkte landerye ($R^2 = 0.96$) as gevolg van die vermenging van die ploeglaag tot op die diepte van bewerking.

Koolstof voorraad tot 1m gronddiepte is bepaal deur middel van die integraal van die genormaliseerde eksponensiele verspreiding, vermenigvuldig met die waarde van C_{org} op die grondoppervlak en op ‘n volume basis uitgedruk as koolstofdigtheid (Cv, $kg{\cdot}m^{-3}$). Die gevolglike voorraadopname is met gemete waardes vergelyk deur middel van ‘n stuksgewyse integrasie van die gemonsterde diepteinkremente om GOK voorraad per area ($kg{\cdot}m^{-2}$) te lewer. Die gemiddelde geskatte fout van voorspelling was 1.2 (9%) en 3.7 $kg{\cdot}m^{-2}$ (21.6%) in grasveld and plantasies onderskeidelik en 1.3 $kg.m^{-2}$ (9.5%) in bewerkte landerye. Verdere verbetering van die modelle en ‘n verlaging in hierdie foute kan verkry word deur die grondtipe inligting as veranderlike in te bring en die funksies volgens grondtipe eerder as landsgebruik te groepeer.

Resultate van hierdie werk is reeds aangebied tydens ‘n seminar by die department Grondkunde, Stellenbosch Universiteit (Ros Mesa et al., 2014), die gesamentlike kongres vir die Suid-Afrikaanse Verenigings vir Grondkunde, Hortologie, Onkruidwetenskap en Gewasproduksie (Rozanov et al. 2015), die Eerste *Global Soil Map* konferensie, Frankryk (Wiese et al, 2013), die 20ste Internasionale Grondkunde Kongres, Korea (Wiese et al. 2014) en is ingehandig vir publikasie in ‘n spesiale uitgawe van Geoderma wat, na aanleiding van die aanbieding by die 20ste Internasionale Grondkunde Kongres, Korea (Wiese et al., 2014), fokus op digitale grondkartering van grondorganiese koolstof.

DEDICATION

This thesis is dedicated to my parents, who taught me to follow my dreams until they become true and for their support in every single moment that I was far from home.

To Andrés, who from heaven enlightens my road and helps me choose wisely.

To my supervisors for the entire support that they give me during the two years that the research lasted.

DEDICACIÓN

Esta tesis está dedicada a mis padres, quienes me enseñaron a seguir mis sueños hasta que se convirtieran en realidad y por su apoyo incondicional en cada momento que estuve lejos de casa. Para Andrés, quien desde el cielo ilumina mi sendero y me ayuda a elegir sabiamente.

Para mis supervisores, por el apoyo que me dieron durante estos dos años de investigación.

PREFACE

When I started working on this topic I had no idea how much influence patience and persistence have in the scientific world. I think at first none of us realize how much work we could do during two years of research, all those hours spent in the laboratory preparing samples, all those analysis that were done during these last couple of years, conferences and many questions. Clearly, when we were digging that first shovel out of the pit or when we were working practically from sunrise to sunset, we did not realize what a contribution we can make when the work comes to completion.

Now, practically two years after that first moment in Greytown I personally realize how much effort the three of us (Liesl, Andrei and I) put into it and I am full of joy that all endeavor may be worth something to the scientific society as well as to ourselves. All fights against hardpans, rocks, paper bags with holes, those thousand samples, cores which would not go in, rental cars and steep slopes are totally worth when I think about all those good moment that I had the opportunity to live with my supervisor, co-supervisor and my colleagues.

None of this would have been possible without the support of companies or people such as Piadelta, Mondi, Lion Match, Sappi and Steve Stamp which showed unconditional support to our research and helped us as much as they could.

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LIST OF SYMBOLS

C_{org} – Soil organic carbon content, %

C_{ov} – Soil organic carbon content, kg·m^{-3}

C_{stock} – Soil carbon stock for specified depth interval Δz, kg·m^{-2}

P – soil porosity

ρ_b – soil bulk density Mg·m^{-3}

ρ_h – density of soil organic matter, Mg·m^{-3}

ρ_m – density of soil mineral fraction, Mg·m^{-3}

ρ_s – weighted average density of soil particles (particle density), Mg·m^{-3}

z – soil depth

LIST OF ABBREVIATIONS

CEC – cation exchange capacity

ODE – ordinary differential equations

SOM – soil organic matter

SOC – soil organic carbon

SPAW – soil plant-available water model

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1. REVIEW AND HYPOTHESIS FORMULATION: STOCHASTIC MODELING FOR SOIL CARBON STOCK ASSESSMENT

1.1 Approaches to Soil Organic Carbon Accounting

Land use change could help to mitigate the effects of carbon emission for sequestering carbon in various ways. Developed and developing countries agreed to account for carbon emissions based on the Kyoto Protocol. The most important article of the protocol related to soil refers to land use, land use change and forestry; which says that emissions are allowed to be offset by demonstrable removal of carbon from the atmosphere. Based on the aforesaid, assessment of soil organic carbon (SOC) is important to accomplish this objective (Geoghegan et al., 2010; Peltoniemi et al., 2006; Petrokofsky et al., 2012; Sleutel et al., 2003). Regarding this concern, just forest clearing is responsible for about 12% of the world's anthropogenic greenhouse gas (GHG) while abandoned land which was used as an agriculture land previously could be responsible for up to 25% of the in human induced emissions (Yadav, 2010). Conventional agriculture often depletes soil carbon pools, for instance; in arid regions a recently established crop could have a SOC stock 50% higher than a similar soil under a crop which was established 10 years prior due to agricultural management, use of different equipment for soil preparation or harvest (Santra et al., 2012). On the other hand grasslands often seem to be continuously accumulating SOC because of the accumulation of organic matter, presence of wild life and few intervention from outsiders (Bach at al., 2011).

SOC inventory for a large area can be time consuming and expensive (Akumu at al., 2013) improving the sampling process or developing estimation models could be of great value (Petrokofsky et al., 2012; Yadav, 2010). However, precise methodologies are being investigated due to possible carbon trading options and to improve accounting of carbon in a way to do facilitate the actual process. To achieve the goal of Kyoto protocol there has to be a precise measurement of SOC stocks and an accurate verification of the amount of carbon (C) sequestered in the soil (Mishra et al., 2009), to do this, direct measurements and soil carbon modelling are needed in any case (Petrokofsky et al., 2012). Factors like input of biomass or degradation will influence the SOC stocks, but soil type and land use may have even more effect on SOC stocks. Thus, the necessity of having accurate approaches, techniques and methods is really important. To calculate SOC stock *Equation 1* is used (Mishra et al., 2009; Van Meirvenne et al., 1996).

$$C_{stock} = \sum \Delta z \cdot \frac{C_{org}}{100} \cdot \rho_b \qquad \textbf{(1)}$$

Where: C_{stock} is SOC stock ($kg{\cdot}m^{-2}$), Δz is the depth increment (m), C_{org} is the SOC concentration (%) and ρ_b is soil bulk density ($kg{\cdot}m^{-3}$) and 100 is conversion of SOC% to fraction.

There are different methodologies to assess SOC. However, the process starts with sampling a specific area for determination of SOC content and bulk density (ρ_b) within a layer's thickness. Samples can be taken using a hammer-driven core (Mishra et al., 2009) or simple soil core samplers (Dar & Sundarapandian, 2013).

The above authors suggest to take several replications from the same depth. Either 3 or 5 different samples taken from the same depth must be mixed together to create a general representative sample for chemical or physical calculations except BD. BD should be determined in individual samples and averaged later.

Wet oxidation (know as well as Walkley-Black method) has become a standard analytical method for soil carbon analysis (Conyers at al., 2011; Dar & Sundarapandian, 2013). Even though, the method itself has suffered modifications since its creation in 1934, it is still a reliable method with strengths and some limitations (Heanes, 1984). Walkley-Black uses the heat of dilution from the addition of sulfuric acid to potassium dichromate solution to enhance the oxidation of the organic matter present in the sample. However, spectral methods have been used lately instead of using its original titrimetric finish which is titration of unreacted dichromate (Conyers et al., 2011). Another option to account for the concentration of carbon is using the dry combustion at 900°C – a method used in a C-N elemental analyzer (Mishra et al., 2009). Same study points out that to assess SOC stocks it is critical to determine the distribution of SOC concentration with depth and adds that the final amount of SOC would be the sum of all the SOC stocks calculated for all the depth increments.

Most of the problems with assessing SOC stocks are associated with the depth of sampling. Many studies have decided to analyze just the first 30cm (Bach et al., 2011; Petrokofsky et al., 2012) of the soil profile and therefore there are some physical and chemical processes which are disregarded in deeper layers, for instance; earthworm's activities or leaching. These processes actually provoke movements of carbon within the profile while sampling just the first 30cm tends to be sparse and insufficient for the constant change that this layer shows (Petrokofsky et al., 2012). For the reasons above it is important to model SOC stocks and find the most efficient way to account for them.

Nowadays, there is no existing method able to calculate SOC stocks taking just one sample and extrapolating data deep down the profile. This, considering that the simplest method of soil carbon stock assessment down to 1m depth as formulated in Century model requires measurement of bulk density and carbon content at the surface and at the depth of 1m, we can formulate the main objective of this study:

- **Develop a model that would quantify the SOC stock down to 1m depth based on only one sample per soil observation point using a single measurement of SOC content and bulk density close to the soil surface.**

1.2 Modeling distribution of soil organic carbon with depth.

Normally, there are two approaches to modelling which are used to describe a dynamic system; processes formalization or statistical approaches. In the first case the model is called deterministic meanwhile the latter model is called stochastic (Rios & de Mello, 2013). Roughly, stochastic modeling has the purpose of estimating the probability of outcomes within a prevision to predict what conditions might be like under different situations and the random variables are usually constrained by historical data, even though the system could end up giving conflicting solutions (Krone, 2004). Nowadays, most of the systems related to soil rely on deterministic models based on ordinary differential equations (ODEs). However, there is an interest on developing stochastic modeling techniques (Steijaert et al., 2010). Jones et al (2007) have expressed a particular view defining stochastic models as random due to variables present which can be characterized by a probability density function. Furthermore, same study has added that existence of uncertainty in measurements of soil carbon and other variables produced an uncertainty in the model itself. The spatial correlation is expressed as a covariance matrix among all state variables giving to stochastic modeling the power to correlate state variables over space. As a result of these processes there are always some uncertainties in the obtained data when the inputs are varied (Jones et al., 2007).

At present, models to predict SOC are used in different studies around the world. SOM models are used to assess the impact of global change on SOM and also CO_2 feedback into the atmosphere. Even though SOM models can predict some other soil characteristics, SOC is one of the most important parameter due to its influence on agriculture production and land use change on carbon sequestration/emission. This, based on the direct relationship between SOC and SOM which interact with micro and microorganism plus other living agents such as plants and small insects. Moreover, running a SOM model requires an existing dataset to verify its validity of prediction and as a result one could be able to predict reliable long-term SOM changes if the model gives accurate data using the existing dataset (Smith et al., 1997).

One of the most common prediction models is Century which is able to simulate nutrient dynamics, such as nitrogen; and carbon content. Roughly, it is modelling a plant-soil system which is the interaction between the two related mainly to nutrients and water (Tornquist et al., 2009). Even though Century model has shown to be effective for forest ecosystem, correcting the sub-models present in Century like “ecology” or “forested system” the result would be more accurate (Bortolon et al., 2011; Kelly at al., 1997). Tornquist et al. (2009) describes some needs that the model could require such as, minimum input dataset for running for the model with such parameters as precipitation, temperature, soil texture, bulk density and nutrient stocks. Moreover, Century model seems to assess the overall changes in SOC (Tornquist et al., 2009), but only if the study is placed in an average size catchment like a farm due to high uncertainty on a regional scale (Bortolon et al., 2011).

Another well-known model often used in studies regarding soil carbon is Rothamsted carbon model (RothC). This model uses climate, clay content and crop management as main inputs to predict changes in SOC under different land uses (Francaviglia et al., 2012). There are options for running RothC, for instance RothC-26.3 run in a reverse mode calculating the amount of inputs necessary to reach a certain amount of SOC for a particular soil or it can predict the amount of carbon based on the input that the user provides to run in the software (Coleman et al., 1997). Even though Smith et al. (1997) suggest that RothC gives acceptable results another study presented wide discrepancies between the measured and modelled data (Coleman et al., 1997).

There are many other models which could be used for modeling carbon assessment, for instance CANDY, DNDC, DAISY or NCSoil are valid options to assess SOC stocks and how they vary over time. However, models such as SOMM, ITE or Verberne could show significant larger model errors (Smith et al., 1997).

Nevertheless, stochastic models for carbon assessments are not the only ones used in agriculture. There are other models associated with agricultural inputs/outputs, e.g. soil water models or crop production (Bai et al., 2008).

Soil water balance models are normally stochastic, even though a conceptual model is simply based on its not requiring complicated parameters while not losing their predictive value. The model applicability is conveniently used to monitor soil water content in root zone of different crops (Panigrahi & Panda, 2003).

Soil water balance models should always be at least in some part stochastic due to different parameters which cannot be predicted such as rainfall or temperature. As a result the model carries certain unpredictability and variability inherent to storage-discharge relationships. Surely, this kind of model has some deterministic parameters in the model, for instance evapotranspiration, runoff or drainage. However, the final result obtained using the model will depend on its aforesaid stochastic inputs (Verma at al., 2011). Some other models also include root growth and root activity as important factor within modelling processes (Panigrahi & Panda, 2003).

Vertical distribution and quantity in soil water balance models are influenced by land use and crop characteristic. The vertical distribution of water is influenced by soil texture throughout the profile, but root growth is also influenced by clay content. The results of modelling water content are useful seasonally or at any given time (Wang et al., 2013). A key comparison between soil carbon models and soil water balance models is based on time, even though both are mainly stochastic models, soil carbon is used in long-term studies due to slow biological process (Petrokofsky et al., 2012). However, the active pool of SOC is highly influenced by short-term processes such as, organic matter decomposition which has different groups of organisms at different stages. On the other hand, soil water could be modelled at any time because water is always moving due to different factors explained above, but it is not divided by stages (Verma et al., 2011; Wang et al., 2013).

Empirical modelling of soil hydraulic properties is based on texture and organic matter. The Soil-Water-Air- Plant system (SPAW) model is able to analyze different data sets especially those of agricultural hydrology and water management (K. Saxton & Rawls, 2006). Moreover, the field hydrology includes many different concepts which are actually estimated by SPAW model, for instance; water holding capacity of every layer of one specific soil, climatic descriptions or annual crop growth (Saxton et al., 2006).

Determination of soil water tension and conductivity are closely related to moisture which is really hard to determine either in the field or in the laboratory, then gravel and salinity are used for adjusting density while soil texture and organic matter are included (K. Saxton & Willey, 2006). On the same research, Saxton & Willey (2006) describe an estimating method for soil water holding capacity based on the equations which are able to depict soil tension and conductivity relationships versus moisture, but using sand and clay textures and organic matter as independent variables. Furthermore, the description of the SPAW model refers to the capability of the model to give accurate results with wide ranges of either clay or sand in the soil. The model can carry samples with a content of clay between 0-60% and 0-95% of sand content. Nevertheless, other authors have added corrections which incorporate compaction, gravel and salinity effects (K. Saxton & Willey, 2006).

Organic carbon content can also be used as part of SPAW model due to a conversion factor which is helpful and reliable at low SOC concentrations. The factor of conversion is 1.724

considering the assumption that all kind of organic matter contains 58% of organic carbon (Howard, 1965).

Saxton & Ralws model base on texture have been found the most accurate among eight different models which use texture, bulk density and organic matter as parameters. Further, one of the main advantages of this method is its input range based on soil texture, only requiring sand and clay fractions, and organic matter content (Sung & Iba, 2010). Nevertheless, Sung & Iba (2010) suggest calibrating the model for specific area because of different soil types.

Another parameter that the SPAW model is able to predict is saturation of the soil at 0 Kpa, which reflects total soil porosity. Soil porosity is a key factor in any agricultural activity due to its influence on root growth because the space provoked by the pores allow roots to breath and eliminate carbon dioxide from the micro-environment underneath the top soil (Willard, 1957). Furthermore, there is a close relation between bulk density and porosity in the soil being inversely proportional. That means, while bulk density is increasing with depth, porosity is decreasing with it (Kizilkaya & Dengiz, 2010).

From this analysis of literature we can conclude that a stochastic model of vertical SOC distribution, may be of little use in modelling changes in SOC over time, but may be successfully used for mapping and monitoring the changing conditions using regular ground observations. To suit this purpose we can formulate **the following objective**.

- **Focus on stochastic modeling describing the average depth-distribution pattern and quantifying the standard deviations in a combined behavior of BD and SOC content with depth.**

1.3 Bulk density, its relation to other soil properties and distribution with depth.

Modeling the change in bulk density with depth may be of particular importance. Allen et al (2005) pointed out that, although bulk density is an important parameter normally, it is not measured because it is a time-consuming method and based on the same reason it is not sampled unless the main focus of the research is to develop carbon stocks through a survey. Further, the engagement of soil science and engineering have developed *in situ* devices based on gamma-ray attenuation and electromagnetic induction which would help in future to map soil bulk density (Allen et al., 2005).

Apart from changes in the land use or transitions from natural forest to agricultural uses, there are also other important factors to consider when bulk density is determined. Vertisol soils as a rule shrink or swell depending on its moisture content due to the amount of clay content; this does not affect carbon content and its relation to depth, but bulk density, ρb is affected owing to compaction or expansion of a determined sampling volume. Even though C content can remain the same, probably bulk density (BD) will vary substantially with various stresses (Gifford & Roderick, 2003). Other studies have shown that the bulk density was not affected by land management below 20cm also using the “equivalent mass method”, which authors claim is more accurate compared to using fixed depth increments (Ellert & Bettany, 1995; Gifford & Roderick, 2003). On the other hand, a study conducted in Sweden, Poland and Finland suggests that BD is strongly related to soil types and the values can be fitted in high or low values associated with specific kind of soils. Relative BD has been suggested to calculate the compactness of each soil; some of these methods are Proctor test and degree of compactness. The first one is referred to the use of a certain amount of impact energy placed while the second is based on crop yield, drainage and field bulk density (Keller & Håkansson, 2010). The same study adds that bulk density in the field needs to be measured along with water content.

As bulk density can be strongly altered by different vegetation or land use (Davidson & Ackerman, 1993; Throop & Archer, 2012), it is critical to determine its value and extrapolations might lose accuracy, affecting the final SOC stocks which need to be transformed from concentration values to units of volume (Throop & Archer, 2012).

Soil texture, still is the driving force in determining bulk density. It is important to model, adjust or interconnect to any other soil property (Nemes & Rawls, 2004). Moreover, Keller and Håkansson (2010) claims that bulk density can be calculated using organic matter content and particle size distribution getting an accurrate result similar to the core method.

Considering that soil survey results often contain data on soil texture (particle size distribution) and the difficulty of measuring soil bulk density it may be interesting for mapping purposes to derive the information on soil bulk density from soil survey data, while only measuring SOC content for the purpose of carbon accounting. The most successful and widely used model by Saxton and Rawls was developed for soils with SOM content not exceeding 7%, while in our study area higher values of SOM (between 11 and 15%) are common close to the surface. To test the applicability of SPAW model, which does not take into account the mineralogy of clay, for prediction of bulk density from texture in the study area we can formulate **the following objective**:

- **Test the the predictive value of SPAW model for determining the vertical distribution of bulk density from particle size distribution and SOC content in soils with high SOC concentrations.**

1.4 Modeling soil carbon stocks

Simultaneously modeling both SOC content and bulk density may be a reasonable approach. Models have been widely used lately to facilitate the interpretation of the results and also land uses have been separated because of variability in SOC stocks (Martin et al., 2011; Saby et al., 2008). According to Jobbagy and Jackson (2000), using mathematical functions, as it is shown in Table 1, one can extrapolate from shallower to deeper layer characterization of SOC vertical distribution. In addition, mathematical functions which explain vertical distribution of SOC for some soils have been made for the first meter, but normally they have not been evaluated after the extrapolation (Jobbagy & Jackson, 2000; Kempen at al., 2011). At national level most countries use global soil database to estimate SOC storage, which has become a problem because there are only a small number of profiles belonging to the area and there are different soil depths used in the different estimations, which made this estimates inaccurate and impossible to compare with other studies around the world (Yang et al., 2007).

Table 1. Functions used to describe and extrapolate SOC profiles. Models are able to describe either the cumulative content of SOC or SOC density as a function of depth (Jobbagy & Jackson, 2000).

Model†	Equation‡	Flat distribution §	Significance cases (%)‖	Mean predictive error (kg/m²)¶ 0–30 cm	Mean predictive error (kg/m²)¶ 100–200 cm
Log–log, cumulative	$\log Y = K \log d + I$	$K = 1$	84	0.42	3.91
Log–linear, cumulative	$\log Y = K d + I$	$K = 1$	76	1.23	13.83
Log–log, non-cumulative	$\log C = S \log d + I$	$S = 0$	84	0.99	2.00
Log–linear, non-cumulative	$\log C = S d + I$	$S = 0$	76	1.73	10.37
Beta	Y (proportional) $= 1 - \beta^d$	$\beta = 1$	63	12.13	44.50

† Logarithm transformations are base 10.

‡ Each function has a single slope parameter that describes how steep the distribution of soil organic carbon is, independent of total carbon content. The beta model used relative cumulative values, whereas the other models can use either absolute or relative values without affecting the slope. The slope parameters K, S, and β characterize relative rates of decrease with depth, and the intercept I characterizes the absolute content of an individual soil profile.

§ Slope values for a flat distribution, in which soil organic carbon density is constant with depth.

‖ Percentage of soil profiles in which there was a significant ($P < 0.05$) fit for the model with actual data for 0–100 cm.

¶ Ability of the model to predict organic carbon content at 0–30 cm and 100–200 cm depths, expressed as the mean predictive error (MPE $= (\Sigma_n [\text{observed}_i - \text{predicted}_i]^2)/n^{½}$).

The wide use of new sophisticated models and the expanding capability of computing software allow the representation of the variability of some soil properties with depth is becoming a necessity, based on the fact that soil properties vary with depth and also across the landscape. Data during such studies is normally collected by horizon when often it may be better to choose fixed depth ranges. As a result, splines and continuous depth functions are being used to represent depth-distribution of key soil parameters (Odgers et al., 2012).

Kempen et al (2011) point out those soil properties which vary with depth in predictable manner and can be described using exponential decay functions or splines. In the same research, it has been explained that most of the areas with strong human influence or the soil profile with contrasting parent materials these discontinuities occur. Moreover, even without human influence these discontinuities can occur with the presence of a sharp boundary between eluvial and illuvial horizon in a podzol. Depending on soil-forming processes the applicable function may be specific to soil type (Kempen et al., 2011).

$$C_V(z^*) = C_a \; exp(-kz^*) \qquad \textbf{(2)}$$

Where Cv(z*) is SOC content volume baseis (Kg/m³), z* being depth from the top of the model profile (m), C_a is the SOM content at the top of the model horizon, k (m^{-1}) is the rate of SOM decrease with depth.

The work of Meersmans et al. (2009) reveals the first research based on tillage land and how human influence on soil formation and how SOC vertical distribution could be modelled. The research asserts that same function can be used as a constant SOC density until tillage depth. Meanwhile, using an exponential decay function is possible to model the vertical distribution of SOC density for the rest of the profile. As one can infer in *Equation 4*, SOC depth distribution in tilled lands is different from the no-till soils. Below the plough layer the SOC shows an exponential decline with depth, while the SOC remains constant within the cultivation depth.

$$\begin{aligned} z < \mathrm{td} : \mathrm{SOC}(z) &= \mathrm{SOC}_{\mathrm{surf}} \\ z > \mathrm{td} : \mathrm{SOC}(z) &= A \cdot e^{\alpha \cdot (z - \mathrm{td})} + \mathrm{SOC}_{\infty} \end{aligned} \quad \textbf{(3)}$$

Where z is depth (m), td is tillage depth (m), SOC(z) is SOC mass density at depth z (Kg C m^{-3}), SOC_{surf} is SOC mass density (Kg C m^{-3}), SOC_{∞} is SOC mass density (Kg C m^{-3}) at the bottom of the soil profile and α is a constant which determines the shape of the exponential part of the curve (Meersmans et al., 2009).

1.5 Hypothesis, aim and objectives

The purpose of this modelling is to substantially reduce the required number of samples and analysis by limiting observation to soil surface and completely excluding excavation of soil profiles or deep core augering. The secondary aim was to assess the suitability of SPAW model (also known as Saxton & Rawls model) for bulk density predictions, which could be used instead of core sampling.

1.5.1 The hypothesis

of this study is formulated as follows:

The vertical distribution of volumetric soil carbon content may be described by a land-use-dependent exponential decline function. In such case, to calculated the soil carbon stocks to the depth of 1m it is necessary and sufficient to know the coefficients for a function describing the vertical distribution of the volumetric carbon content under specific land use and the value of volumetric SOC content at the soil surface.

1.5.2 The aim.

- **Develop the models that would quantify the SOC stock down to 1m depth based on only one sample per soil observation point using a single measurement of SOC content and bulk density close to the soil surface for three selected land uses (forestry, grasslands and cultivated croplands).**

1.5.3 The objectives

Were formulated to test the above hypothesis:

- Focus on stochastic modeling describing the average depth-distribution pattern and quantifying the standard deviations in a combined behavior of BD and SOC content with depth.
- Determine the best possible continuous functions to describe the pattern of distribution with depth for volumetric soil organic carbon content from analysis of samples collected in the field.

Considering the scarcity of bulk density data in the national and local databases, additional objectives were formulated to test the reliability of using soil texture estimates for bulk density prediction in relation to soil carbon accounting.

- Assess the accuracy of predicting bulk density using SPAW model for soils of known texture and soil organic carbon content.
- Develop multiple regression functions using the same input parameters as the SPAW model and compare the outputs to multiple regressions taking sample depth into account as well.
- Assess the possibility of improving the SPAW model output for soils with very high organic matter content (exceeding 7%) by analyzing the existing model parameters and adjusting them to factor in the effect of high organic matter content on soil bulk density.
- Develop regression equation to customize SPAW model outputs for the study catchment conditions using experimental observations.

2. STUDY SITE, MATERIALS AND METHODS.

2.1 Site description

Greytown is located on the banks of the Umvoti River, in the province of KwaZulu-Natal (KZN), South Africa. Two catchments were selected for this study with the main focus on the southern catchment containing the Mvoti vlei nature reserve (Fig 1.).

All site description maps were taken from an overlap of the QGIS layer on a Georeference System Software; in case of this study the one used was Google Earth which uses WGS84 geodetic datum and that in turn shows a simple cylindrical projection. The location map, as one can see in Figure 1, shows the two catchments used for the study.

Figure 1. Overlay of the QGIS shape-file of the catchment on Google Earth. The study area is located in the reaches of Mvoti River, KwaZulu-Natal Province, South Africa.

The climate varies along the altitudinal gradient due to the complex topography, but Greytown could be described as a warm temperate climate with dry season in winter, although colder than cities or towns close to the Indian Ocean. Normally, rainfall is close to 900 mm per annum mainly falling in summer months from November to March, while the highest monthly-averaged day temperatures are reached in January (28°C). During its dry winter (June to September), Greytown is particularly cold in comparison to the rest of the province with a minimum of 11°C, but in the bottom of the valley, the temperature can fall below 0°C and frost is common.

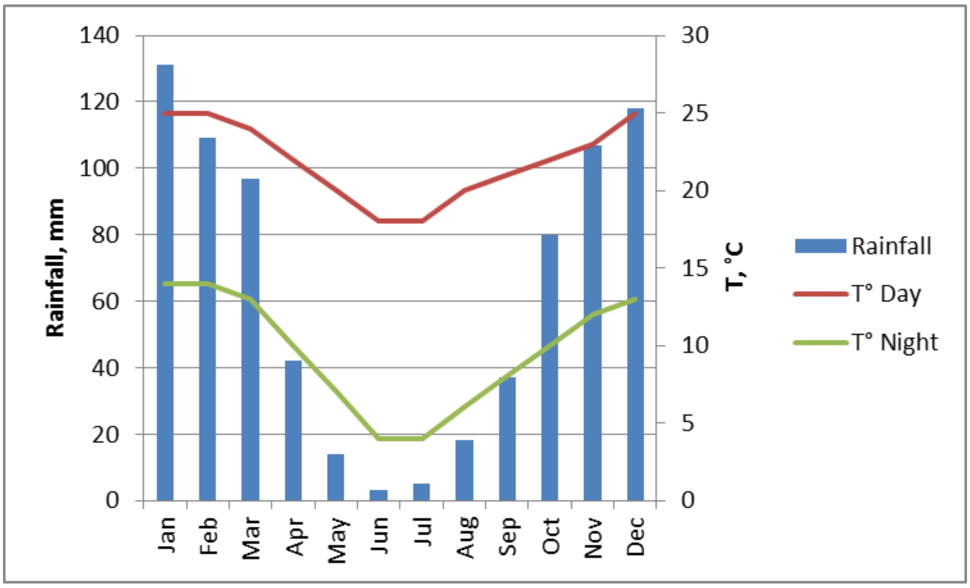

Figure 2. Mean monthly rainfall, day and night temperatures: Greytown (South African Weather Bureau data).

The geology in Greytown and surrounding areas is a typical Karoo setting with two parent materials dominating the study catchments. The first of them was shale which is a fine-grained clastic sedimentary rock composed of mud that is mix of flakes of clay minerals and secondly, dolerite which is a mafic, holocrystaline sub-volcanic rock. A small band of sandstone occurs in the middle of the catchment, but this area was avoided in soil sampling and the main focus fell on shale and dolerite materials.

The native vegetation is represented by a mosaic of grasslands and indigenous afromontane forest. However, these days agriculture and plantation forestry have taken over a large proportion of the land.. Plantations of Eucalyptus and Pines are the most common in the area along with maize grown for grain and seed production. Occasional patches of sugarcane are located in some frost-free areas and the catchment is regarded as the margin of the main sugar-cane-growing area (Fig 3).

Figure 3. The view of the vegetation mosaic and the naturally terraced Karoo (semi-desert natural region of South Africa) topography with alternating steep gradients and flat sills as seen from the top of the catchment.

Fifty profiles (see Addendum A) were dug within the catchments U40A and U40B (see Figure 4). The distribution and selection of the profile sites were based on land uses and slopes of different sections of the landscape. First of all, the profiles needed to include the three land uses in the study area (around 50% forestry plantation and the rest distributed by commercial farming, and grassland). Secondly, catenas were followed to understand the changes in soil types along the slope of the hill. The profiles were classified using the South African Soil Classification System prior sampling.

A Geographic Positioning System (GPS) was used to reference the spatial position of every profile sampled. The GPS coordinates loaded into QGIS illustrate the profile locations within the study catchments (Figure 4).

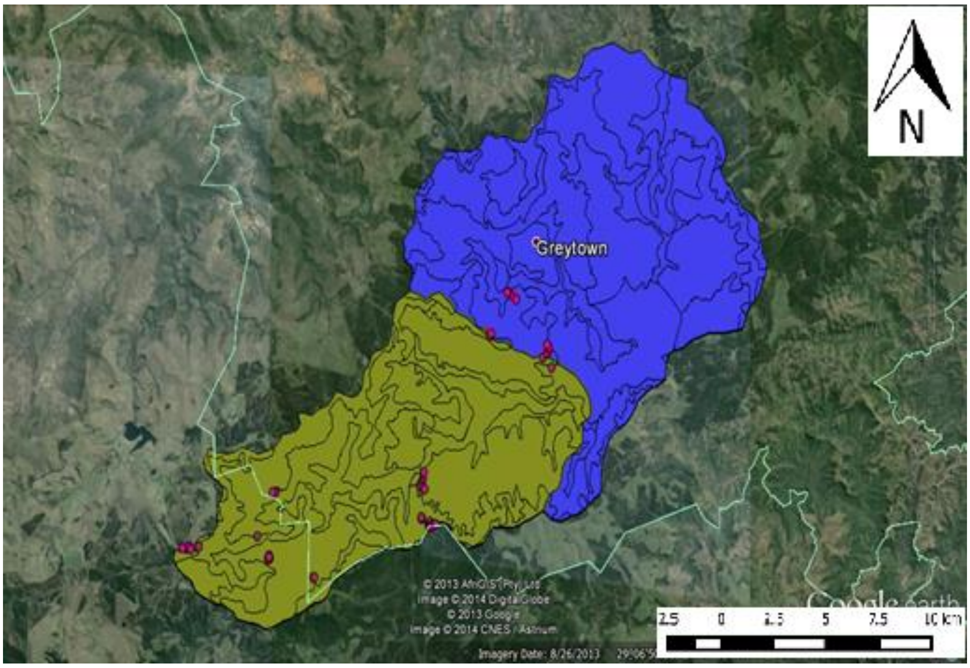

Figure 4. Sampling points distributed within the catchments U40A and U40B.

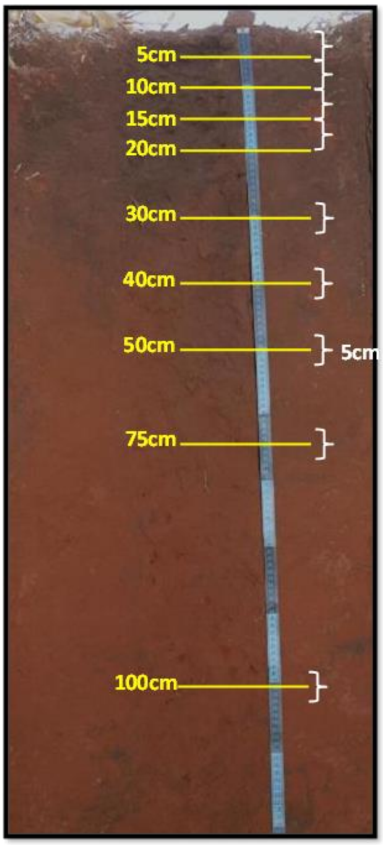

Figure 5. Core sampling increments.

The core sampling was done in triplicate to get more accurate results, especially for bulk density. Depth of sampling was done according to the ease of digging and limitations throughout the profile. Samples were taken at depths of 2.5, 7.5, 12.5, 17.5, 30, 40, 50, 75 and 100cm; based on the fact that the core height is approximately 5cm. Normally, during the process, around 8 or 9 depths were sampled per profile, which, in triplicate resulted in an average of 27 samples extracted for each pit. Each core sample was then put into a paper bag or a plastic bag if the soil was fairly wet.

Cores with a diameter of 52mm and a height of 46mm were used for all sampling purposes, with samples take in triplicate.

Figure 6. The final core volume used for all calculations during this study was 98.05cm^3.

All the samples were oven-dried at 105° for 24 hours in the same paper sampling bags. In the case of plastic sampling bags, the samples were placed on a porcelain dish inside of the oven. Following drying, all (triplicate) samples were weighted with a three decimal accuracy.

2.2 Laboratory procedures.

The bulk density of the samples was calculated for each sample by dividing the oven-dry mass by core volume. The average bulk density was calculated from the three replicates per sampling depth to obtain a single, but more reliable value characterized by standard deviation.

Following bulk density determination, samples were combined per sampling depth and sieved through a 2mm sieve to remove bigger stones, gravel, roots and leaves present in the sample.

Total SOC was analyzed on the combined samples according using the Walkley-Black method described in the Soil Survey Laboratory Methods Manual of the United States Department of Agriculture (Burt, 1992) This method entails wet combustion method based on ferrous ammonium sulphate, $FeSO_4$ titration and an automatic titrator to determine organic carbon content reported as SOC %.

Determination of particle density was done using pycnometer method. The first step is to clean all pycnometers, dry completely and label them depending on the sample used, then determine the weight of every one of them in a three decimal scale (m_0). Later, 10g of soil of each sample was placed in every pycnometer to get the weight anew (m_1). Afterwards, all pycnometers were filled up with distilled water as well as capillarity hole in the stopper is filled with water, it needs to be dry when the stopper is placed because water tends to splash out before to be weight again (m_2). Finally, the pycnometers were filled just with distilled water to be weight for the last time and determine m_3. The equations applied for further calculations are shown in Table 2.

Table 2. Equations used to determine particle density (DCU Manual of Mechanical Engineering)

Equation	**Meaning**
$p = m/V$ (1)	Where p is density, m is mass and V is volume.
$V = m_{H2O}/p_{H2O}$ (2)	Where m_{H2O} is experimentally determined weight of water (empty pycnometer weight subtracted).
$V = m_L/p_L$	Where V is volume, p_L is the unknown density and m_L is the measure weight minus weight of empty pycnometer.
$m_{H2O}/p_{H2O} = m_L/p_L$	Same meanings that were described above.
$V'_{H2O} = m'_{H2O} / p_{H2O}$	Where m'_{H2O} is m_0+m_s and V'_{H2O} is the added water to the sample.
$V_s = V - V'_{H2O} = m_{H2O} - m'_{H2O} / p_{H2O}$	Where V_s is the volume of the measured soil and p_{H2O} is the density of water.
$p_s = m_s/V_s$	Where p_s is density.

Furthermore, the density of water changes due to different temperatures in the working area was also included to apply the last equation for particle density. Water temperature was monitored to correct for variations in water density. Table 3 shows the values of water density close to room temperature..

Table 3. Vales of water density depending on temperature (DCU Manual)

t [°C]	**ρ_{H2O} [g/cm3]**
19	0.99978
20	0.99820
21	0.99799
22	0.99777
23	0.99754

Determination of particle size distribution was done using a particle size analyzer, instead of using the pipette method to determine soil texture.

A further modification to the method was introduced at soil preparation stage. Instead of peroxide treatment, the samples were ignited at 550°C. This temperature was chose to ensure complete combustion of organic matter. However, we have knowingly destroyed some of the clay material, since some clays, like gibbsite present in these soils decompose at 200°C, while others (kaolinite and illite also common in these soils) start losing mass at 400°C. To account for mass loss from clay particles the correction was introduced into the results of particle size distribution obtained from the particle size analyser. Knowing the carbon content determined by Walkley and Black method we could calculate the organic matter content using the van Bemellen factor (1.724).

The correction factor was: LOI – SOC*1.724. This correction factor was added to clay content keeping in mind that mass loss from hydroxides and clays was the total mass loss minus the mass loss from combustion of organic material.

The removal of carbonates was not required in this case due to low soil pH (3.5-6.5). On the other hand removal of iron oxides was done using 50cm^3 sodium citrate - sodium bicarbonate solution. Sodium dithionite ($Na_2S_2O_4$) was added gradually as some of the sample frothed.

Later, samples were heated for 30 minutes on the water bath at 80°C while the suspension was stirred intermittently. Once removed from the water bath, the samples were centrifuged for 15min and the clear supernatant was taken out of the sample using a pipette while the samples turned to a grey colour. The treated samples were passed through a 0.5mm sieve. The sand retained on the sieve was oven-dried at 105°C in a porcelain dish for 24 hours to get the final weight. The weight of sand >0.5mm was added to the weight of san determined by the particle size analyser.

Finally, particle size distribution (see Addendum B) was done using a particle size analyzer, Micromeritics Saturn DigSizer 5200 model (see Figure 3), which determines the size range, or the average, or mean size of the particles in the soil.

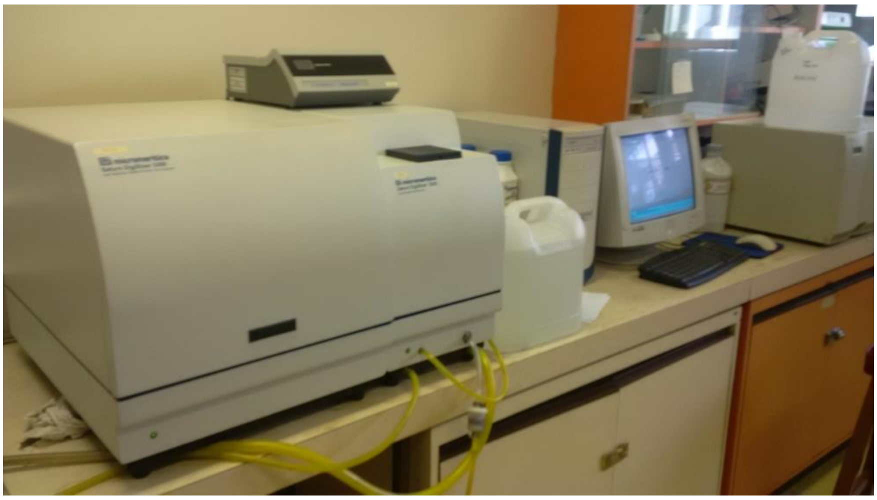

Figure 7. Particle size analyzer by Micromeritics Saturn DigSizer 5200

3. RESULTS AND DISCUSSION

3.1 Modelling volumetric soil carbon content distribution with depth.

In total 46 profiles were selected and grouped according to land use with 17 profiles under commercial crop production, 7 under grassland and 22 under forestry. The soils (Addendum A) are predominantly Oxisols and Entisols according to the Soil Taxonomy (2011) and represent a variety of Inanda, Kranskop, Magwa, Nomanci and Avalon soils as defined in South African soil classification (1999).

The profiles occurring in wetland areas were excluded due to unpredictable behaviour of SOC with depth (Dundee, Katspruit and Champagne soil forms). The two main reasons for the difficulty of SOC stocks prediction in wetlands are:

- Potentially very deep layers of SOC stocks with layers of peat and mineral sediment;
- Common presence of fresh sediment on the surface, which will not allow to correctly model the distribution using the surface sample alone (Fig.8).

Figure 8. Champagne soil buried by recent sediment (profile 15).

The profiles were excavated and sample to the depth of 1m unless manual excavation depth was physically restricted. Volumetric carbon was calculated by multiplying the values of bulk density by carbon content (as fraction) at each sampling depth per profile giving the content of carbon in kg/m³.

3.1.1 Stratified data averaging and normalization.

Stratified averaging was applied to the volumetric carbon content values for the three selected land uses: for every land use an average value and standard deviations were calculated for all the profiles within the group. Those were plotted versus soil depth and modelled with an exponential function. The result of such modelling for the forestry areas is presented in Figure 9, which shows the average distribution of volumetric carbon with depth (r^2=0.98) and allows to rather accurately predict the stock by integrating the exponent curve to the depth of 1m.

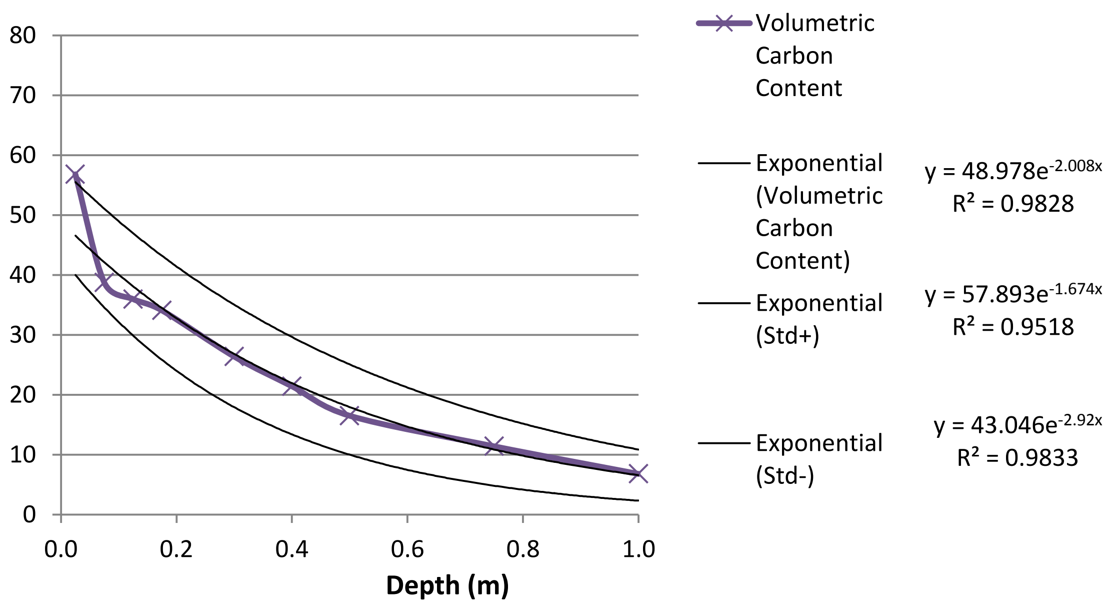

Figure 9. Stratified average volumetric carbon content, kg/m^3: forestry profiles.

In this case, the intercept of the exponent represents the value of the volumetric carbon content at the soil surface.

However, such an approach, though giving a reasonable area-average prediction, may be improved by introducing the variability in organic matter inputs under different land uses. Assuming that the distribution of volumetric carbon concentrations with depth are somehow related to the amount of inputs at the surface (litter, crop residues, etc.) and relationship between above/below ground productivity, the surface concentrations are critical for understanding the whole distribution pattern.

We can use the predictive nature of the exponential function to increase the detail of soil carbon survey by only using the average slope of the function and measuring the intercept (volumetric carbon content) for each observation point in the field.

To achieve that, we have to rescale (normalize) the distribution function. In this case the normalization procedure involved dividing each value by the value observed in the top sample (0-5 cm). The most commonly applied rescaling procedure uses MIN and MAX values in the set to rescale the set to the range of 0-1. In this case we assume that at some depth the volumetric carbon content is nearing 0 and MIN values was set to 0 allowing us to use only the MAX value. It's a very important conceptual decision, which allows us to use only one value at the surface and not measuring the carbon content and bulk density at the depth of 1m, which would have been a requirement used in the Century model, for example. Furthermore, using the value at the surface instead of true MAX value (which may be in some cases, particularly in cultivated land or positions in the landscape that accumulate slope wash, found below the surface) results in some values potentially exceeding 1, which means that potential deviations from exponential distribution will not affect the average behavior of the curve and allow it to break above the value of 1 at the surface, potentially increasing the predictive capacity.

The result is a dimensionless value, which multiplied by the observed value produces the volumetric carbon content in kg/m^3 for each individual observation point. The normalization (rescaling) procedure does not affect the shape of the resultant curve or the correlation coefficients. However, the curve fitting results are slightly different, since we simply can \not possibly measure the value at the depth 0. The average core depth is 2.5 cm and as a result of that the correlation coefficient is slightly reduced. Hence, we voluntarily reduce the accuracy of prediction somehow for the ease of measurement and calculations. The standard deviations at the depth 2.5 are 0, but that is understandable since this value is in fact measured and not modeled.

The volumetric carbon content values of all profiles were normalized by dividing the carbon content at each sampling depth per profile by the value at the surface (core center depth: 2.5cm) for that specific profile. Hence, all volumetric carbon content values were divided by the surface value since the vertical distribution of carbon is decreasing from the top to the bottom of the soil (Meersmans et al., 2009). As Figure 21 shows, even though the r^2 value for volumetric distribution of carbon content under forestry is as high as the normalized value displayed in Figure 8, the volumetric distribution of carbon is a distribution of the complete profile where uniformity is not a priority and where the application of the model would be more difficult to achieve and probably less accurate.

Furthermore, the main reason to apply the normalization was to get a better uniformity on the final results which are based on the top values of every profile. The curves given by normalized values are smoother, better represented by exponential curves and they also have standard deviations narrower than in volumetric carbon content graphs. Moreover, the interception used to represent the data (y-intercepted equal to 1, due to use of surface values as parameters) gives manageable and moldable equations to work with and to apply in a general approach using integrals. However, the most important aim is to be able to predict carbon contents throughout the profile by only sampling the first five centimeters of the soil and thereafter applying the integral of the normalized equation. This approach makes the process of normalization even more important since all values need to be related to the top value to get reliable accuracy in the final results.

3.1.2 Fitting the exponential functions and error estimation

Normalized values were plotted per land use category with Figure 10 showing the carbon distribution, from the top of the profile down to 1m, for profiles under forestry plantation including Eucalyptus (*Eucalyptus sp.*) and Pines (*Pinus patula*).

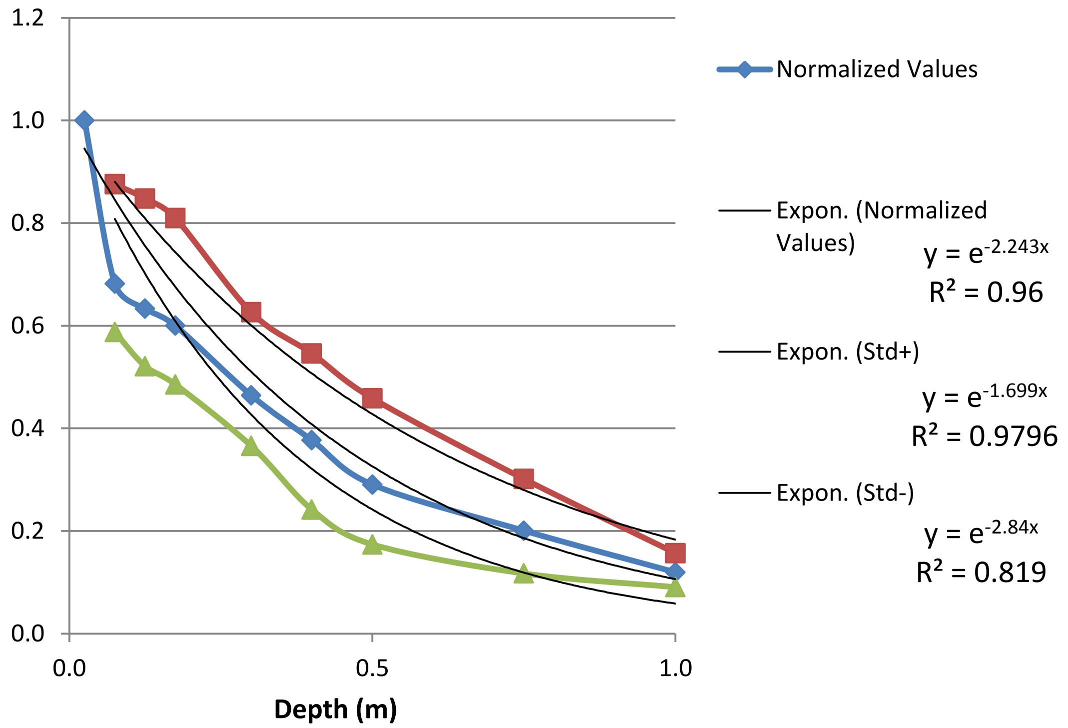

Figure 10. Stratified average normalized volumetric carbon content: forestry profiles.

Carbon stocks were also predicted for both commercial crop production and grassland land uses using exponential curves based on the most appropriate fit and R^2 values. Even though all profiles were also classified and analyzed by soil forms, it was decided to use land use as category due to ease of application, better understanding worldwide and fitting of the curves. However, knowing the soil forms present in the catchment was useful to understand the some of the physical and chemical properties present in the study area.

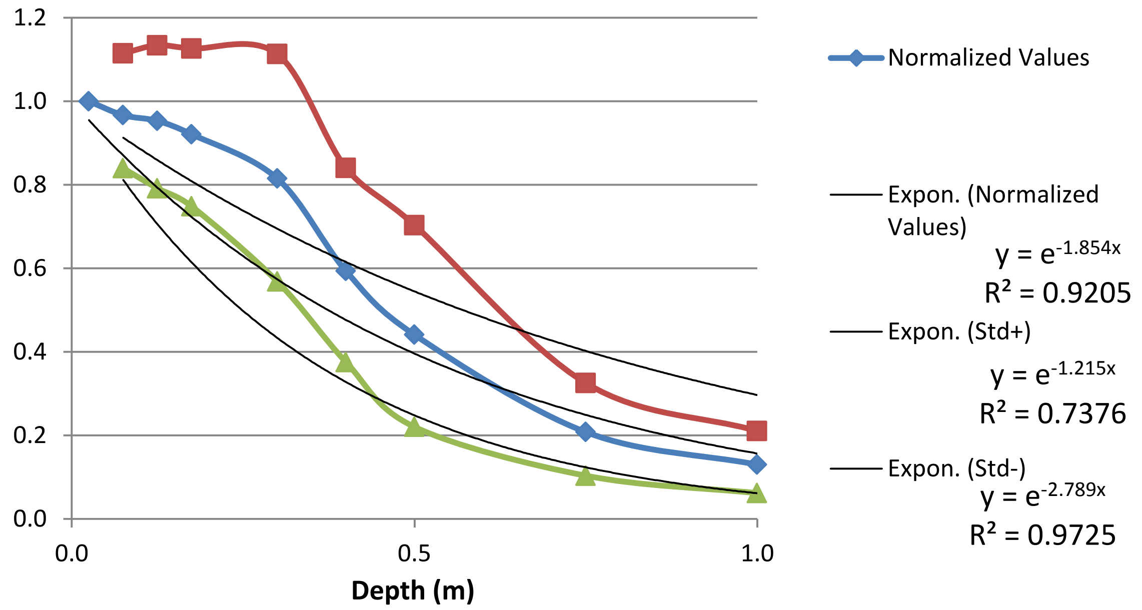

Figure 11. Stratified average normalized volumetric carbon content: cultivated land

Figures 11 and 12 show the distribution of averaged and normalized volumetric soil carbon content through the profiles from the top to 1m deep under commercial crop production and grassland respectively, showing similar behavior as the one made for forestry purposes.

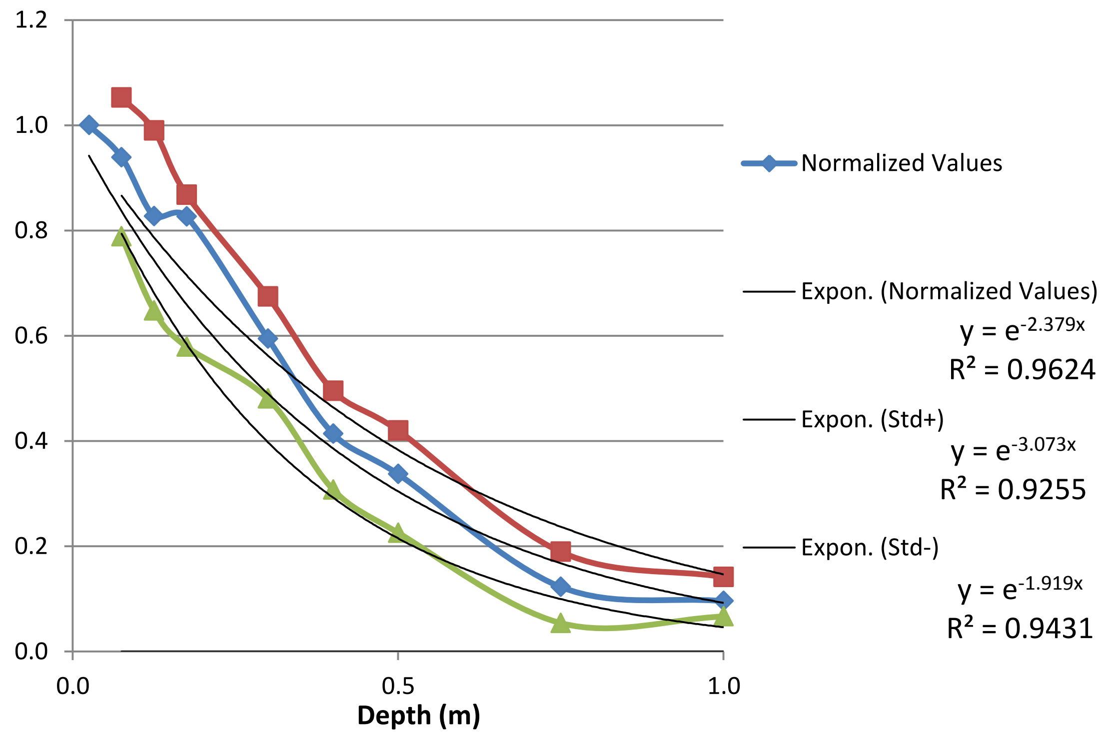

Figure 12. Stratified average normalized volumetric carbon content: grasslands

It is worth noting that the exponent coefficients for grasslands and forests are rather similar (2.38 and 2.24 respectively both with r^2=0.96). On the contrary the coefficient for croplands is much smaller (1.85, r^2=0.92) showing a substantially less rapid decline in volumetric carbon content with depth and lesser reliability of predictions. This may be directly attributed to cultivation in several ways:

- Cultivated lands had lower values of initial volumetric carbon content due to humus mineralization and
- Mixing through the plough layer, quite obvious from Figure 11 as well as
- Different volumes and quality of organic matter inputs.

It is also obvious that a simple exponential curve does not adequately describe the vertical carbon distribution in cultivated soils. In future, other models (e.g. rational function or tangent may be considered if one function is to be used, or a system of linear and exponential equations separately similar to the system suggested by (Meersmans et al., 2009) describing the behavior in the plough layer and the subsoil). Never the less, the average predictions of stocks for cultivated land given below are showing similar errors to predictions for grasslands and forests.

Analyzed and sampled grasslands were located as corridors between plantation forestry and spatial proximity may have a strong effect on the similarity of the distribution pattern observed. The area is located in the mist belt (Ward et al., 1997) characterized by rather uniform climate, though a rainfall gradient from the top to the bottom of the catchment is present. The tillage practices were different in the two farms where maize is produced, with one practicing conventional tillage and the other reduced tillage. Still, the error of carbon stocks estimation for these two practices was comparable to grasslands and less than in forests.

Factors like input of biomass or degradation influence the SOC stocks, but soil type and land use may have even more effect on SOC stocks (Mishra et al., 2009). To calculate SOC stock per sampled layer Equation 4 was used. Thus, the necessity of having accurate approaches, techniques and methods is a key factor (Mishra et al., 2009; Van Meirvenne et al., 1996).

$$Stocks = (z \times C \times Pb)/100 \quad \textbf{(4)}$$

Where stock is SOC stock (tC), z is the sampling depth (m), C is the SOC concentration (g C kg^{-1}) and Pb is bulk density (kg m^{-3}).

The definite integrals were calculated for the exponential equations in Figures 1, 2 and 3. Thus, average of the top value of carbon content for every land use was made with the objective of obtaining representative and accurate volumetric carbon content (Cv). Equation 7 represents the integral created to represent the vertical carbon distribution from the surface to 1m deep, based on the capability to extrapolate values deep down through the profile resulting in accurate and reliable results (Sleutel et al., 2003).

$$\int_0^z Cv \cdot e^{-lz}\, dz = \frac{Cv}{l} \cdot (1 - e^{-lz}) \quad \textbf{(5)}$$

Where Cv represents volumetric carbon content, l represents the slope of the exponential function and z represents the depth of the profile.

The biggest challenge with assessing SOC stocks is based on the wide variety of the depths of measurement used in literature. Many studies have analyzed just the first 30cm (Bach et al., 2011; Petrokofsky et al., 2012) of the soil profile resulting in the omission of the effects of physical, chemical and biological processes (such as earthworm activities and leaching) on deeper layers. These processes induce movements of carbon within the profile while sampling of the first 30cm tends to be sparse and insufficient for the constant change that this layer shows (Petrokofsky et al., 2012). For the aforementioned reasons, it is important to model SOC stocks and find the pattern in the deeper layers.

The integration of volumetric carbon distribution curve to 1m depth accomplished the accuracy needed to predict carbon stocks. Although, according to Sleutel et al. (2003) Walkey & Black gives systematic errors due to its low accuracy, the result of this research are promising as Table 4 shows. Furthermore, the errors using mean depths are not high and any research can rely on using different intervals and not necessarily changes in soil horizons through the profile (Sleutel et al., 2003).

Table 4. Estimation error for the integration of proposed vertical distribution models (Equation 5) compared to stock assessment based on 9 sampling depths per soil profile (Equation 1).

	Farming	**Grassland**	**Forestry**
Measured Carbon Stocks (kg/m³)	13.7	13.4	17.1
Predicted Carbon Stocks (Kg/m³)	12.4	14.7	20.9
Estimation Error (Kg/m³)	***-1.3***	***1.2***	***3.7***
Estimation Error (%)	***9.5***	***9.0***	***21.6***

Table 4 shows that the difference between measured values and predicted values from a slope of the exponential function are fairly close. Unfortunately the datasets used are not large enough to split them into calibration and validation subsets. Subsequently the proposed models were not statistically validated. Sampling of a new validation set may be done in future, but falls outside the timeframe and funding of this work.

Nevertheless, as bulk density can be strongly influenced by different vegetation or land use (Davidson & Ackerman, 1993; Throop & Archer, 2012), it was critical to determine its value without missing any important information due to extrapolations since bulk density error of estimation strongly affects the accuracy of the final SOC stocks which need to be transformed from concentration values to units of area or volume (Throop & Archer, 2012). Based on the previous statement some of the cores could have been taken with pieces of roots which would affect the final average of the corresponding bulk density value and sampling replications are essential.

On the other hand, carbon has always been used in different models over the years. Models have been used lately especially to facilitate the interpretation of the results and also land uses have been separated because SOC stocks variability is much higher in forest lands compared to cultivated land (Martin et al., 2011; Saby et al., 2008).

The exponential carbon depth model appears to be the most accepted at present, even though there are different ways to approach a model of this kind. Nevertheless, one of the disadvantages of exponential functions is that they are susceptible to local changes, hence many models will be applicable locally (Minasny et al., 2006). However, most of the models existing nowadays rely on the use of splines which use different inputs already existent from previous soil surveys in comparison to the exponential functions which use normally three parameters (Minasny et al., 2006). According to the same authors, the lack of information on the application of splines could occur which normally goes into a tedious process of interpolation using co-kriging to obtain the rest of the information needed. On the other hand, Jobbagy and Jackson (2000) used mathematical functions to show that extrapolation from shallower to deeper soil layers can be helpful to characterize SOC vertical distribution. In addition, mathematical functions which explain vertical distribution of SOC for some soils have been made for the first meter, but normally they have not been evaluated after the extrapolation (Jobbagy & Jackson, 2000; Kempen *et al.*, 2011). Nevertheless, this study based on exponential functions has been created with the purpose of generating new information and it is not based on any previous survey results, but purely on sampling in the field with determined land uses and soil forms. Moreover, one of the main objectives of this research is to assist and help new researches on the assessment of carbon, even though the model needs to be calibrated for each locality. As Jobbagy and Jackson (2000) suggested in their study, mathematical approaches are totally possible and applicable in assessment of soil organic carbon. Using an integral to predict the total carbon stocks of every land use is an improvement to the efficiency of any activity related to the topic since this study based the process on sampling, accounting and assessing SOC in the top soil.

The choice of grouping the profiles in three different land uses instead of using soil forms is based on the variability of soils found within the catchment which generally had similar characteristics such as, humic A horizon and a parent material of either shale or dolerite. According to Kempen et al (2011), depending on soil-forming processes the applicable function can change between different soil types. According to Wiese et al (2015), the Co-variance with land use is close to 64%, while with soil types - over 81%. In case of absence of detailed soil maps land use grouping alone may be used, though with lower degree of confidence and precision. Furthermore, using land use information would facilitate taking samples from the field, if for example; the farm or plantation does not have any information about soil types. Moreover, the use of land use as a main factor makes the process faster to have a general representation of a new project. The statistics supporting the use of land use are shown in the Addendum E.

Other authors like Meersmans et al (2009) claimed that the same function can be used as a constant SOC density until tillage depth. Meanwhile, using an exponential decay function is possible for modelling the vertical distribution of SOC density for the rest of the profile. However, during this research the application of this theory gave no satisfactory results due to lack of appropriate fitting using the exponential function and also the standard deviation tended to be extremely high in comparison to the normalized function method proposed further in the study.

Even though the results are promising, overestimations in the plantation forestry may have been a result of the presence of litter at the top of some cores. Moreover, cleaning the litter from the top of the soil can get complicated even using shovel or a sharp knife when the plantations reach more than 10 years and the decomposition of organic material has started leading to an unclear separation between litter and soil. The optimal sampling depth and volume for the topsoil sample may be explored in future as a separate study.

Since SOC inventories for a large area can be time consuming and expensive (Akumu at al., 2013) either simplifying sampling processes or developing estimation models could be of great value, especially for developing countries which have other priorities (Petrokofsky et al., 2012; Yadav, 2010). One of the main objectives of this research was to improve the existing process. For instance, activities such as bulk density sampling could take over 3 hours per profile including digging and sampling down to 1m especially hard to reach areas like forests. Moreover, using this technique has an influence on the budget of any future project by limiting expenses on analyses, since only the first five centimeters are sampled of any soil belonging to the three land uses. Even though the method has a small estimating error, it could help optimizing the accounting process of carbon in the soils especially in countries which are involved in the Kyoto protocol where new models need to be developed for assessing carbon stocks (Petrokofsky et al., 2012).

The main conclusions from this section may be formulated as following:

- Exponential decline model of normalized volumetric SOM distribution adequately describes the average observed distributions with depth.

- A single observation of SOM content and soil bulk density conducted in triplicate close to the soil surface is sufficient to estimate the SOM stock down to the depth of 1m. Knowing that the calibration of the model is necessary for each area due to different soil types and climate.
- The error of estimation on average is under 10% of the value for grasslands and croplands, while in forestry areas, due to high variation from average the error increases to 20%.

3.2 Modelling soil bulk density vertical distribution in the soils of the KZN midlands from particle size distribution and SOC content.

In soil carbon stock assessments it is quite common to estimate bulk density from soil texture instead of direct measurement. The main reason is that texture information is often available from soil survey databases. However, one should keep in mind that such texture information is often the result of rapid field assessment by feeling texture by hand rather than the results of particles size distribution analysis. The latter, in fact, is a much more lengthy and expensive procedure than direct bulk density measurement.

3.2.1 Introducing the software and formulating objectives.

The soil-plant-air-water model (SPAW) model is a set of empirical linear correlations derived by Saxton and Rawls in 1986 (K. E. Saxton & Rawls, 2006) from the USDA soils database. The module used in this study was the soil water characteristics (SWC) which is part the of the SPAW software. SWC uses sand content, clay content and organic matter content to predict saturation point at 0kPa, which roughly equals total porosity (excluding the air-locked pores).

Here one should note that Equation 5 in Table 5, where the Θs is calculated has a very low correlation coefficient of 0.29. The porosity value is used to calculate bulk density ρ_N using a fixed value of particle density (2.65 Mg/m^3) from equation 6 given in Table 5.

Table 5. Regression equations of the Saxton and Rawls model with correlations coefficients (r^2) and standard deviation given next to the equation (K. E. Saxton & Rawls, 2006).

	Moisture Regressions		
θ_{1500}	$\theta_{1500} = \theta_{1500t} + (0.14 \times \theta_{1500t} - 0.02)$ $\theta_{1500t} = -0.024S + 0.487C + 0.006OM + 0.005(S \times OM) - 0.013(C \times OM) + 0.068(S \times C) + 0.031$	0.86/0.02	1
θ_{33}	$\theta_{33} = \theta_{33t} + [1.283(\theta_{33t})^2 - 0.374(\theta_{33t}) - 0.015]$ $\theta_{33t} = -0.251S + 0.195C + 0.011OM + 0.006(S \times OM) - 0.027(C \times OM) + 0.452(S \times C) + 0.299$	0.63/0.05	2
$\theta_{(S-33)}$	$\theta_{S-33} = \theta_{(S-33)t} + (0.636\theta_{(S-33)t} - 0.107)$ $\theta_{(S-33)t} = 0.278S + 0.034C + 0.022OM - 0.018(S \times OM) - 0.027(C \times OM) - 0.584(S \times C) + 0.078$	0.36/0.06	3
ψ_e	$\psi_e = \psi_{et} + (0.02\psi_{et}^2 - 0.113\psi_{et} - 0.70)$ $\psi_{et} = -21.67S - 27.93C - 81.97\theta_{S-33} + 71.12(S \times \theta_{S-33}) + 8.29(C \times \theta_{S-33}) + 14.05(S \times C) + 27.16$	0.78/2.9	4
θ_S	$\theta_S = \theta_{33} + \theta_{(S-33)} - 0.097S + 0.043$	0.29/0.04	5
ρ_N	$\rho_N = (1 - \theta_S)2.65$		6
	Density Effects		
ρ_{DF}	$\rho_{DF} = \rho_N \times DF$		7
$\theta_{S\text{-}DF}$	$\theta_{S-DF} = 1 - (\rho_{DF}/2.65)$		8
$\theta_{33\text{-}DF}$	$\theta_{33-DF} = \theta_{33} - 0.2(\theta_S - \theta_{S-DF})$		9
$\theta_{(S\text{-}33)DF}$	$\theta_{(S-33)DF} = \theta_{S-DF} - \theta_{33-DF}$		10

The model also offers three parameters for calibration proposes: compaction (Equation 7, Table 5), salinity and gravel content. (Figure 13).

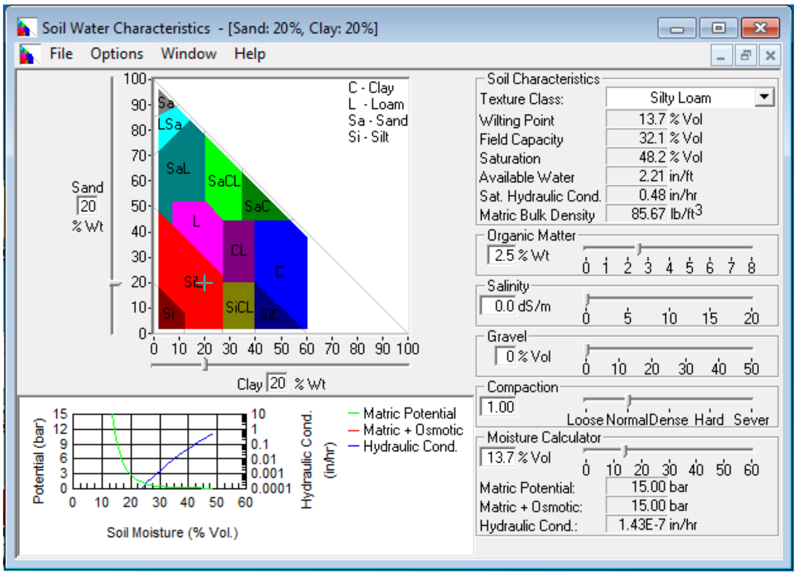

Figure 13. Soil Water Characteristic software to get bulk density and porosity.

The model requires manual input for each sample. The results of model calculation for each sample were recorded in MS Excel splitting them later into three different groups corresponding to three land uses; farming, plantation forestry and grasslands. Bulk density and porosity were calculated from the model and compared to observed values from the field. Considering that the Saxton and Rawls model is based on the USDA database with soils ranging from polar to subtropical regions, locally developed correlations often produce better results with higher correlations and lower errors of estimation. The authors also limit the model to soils with less than 7% organic matter (4% SOC). Considering that soils in the study area often substantially exceed the value of 4% SOC in the top layer, the following objectives were formulated:

- Establish the effect of soil particle density content on SOM density and correct the particle density value in the Saxton and Rawls equation.
- Develop local multiple regressions to calculate porosity based on parameters used in Saxton and Rawls equations (sand, clay and organic matter content) to compare the results with SPAW model outputs.

Experimentally observed values of porosity were calculated from bulk density and particle density determinations. Results obtained from Saxton & Rawls model and multiple regressions models were compared to observed values using various tests available in Statistica software.

3.2.2 The effects of SOC content on soil particle density.

Experimentally determined particle density (ρ_s) was plotted against soil carbon content determined on weight basis by Walkley and Black method for all the samples used in this study irrespective of sampling depth and separated into three groups: Forestry, Farmland and Grassland.

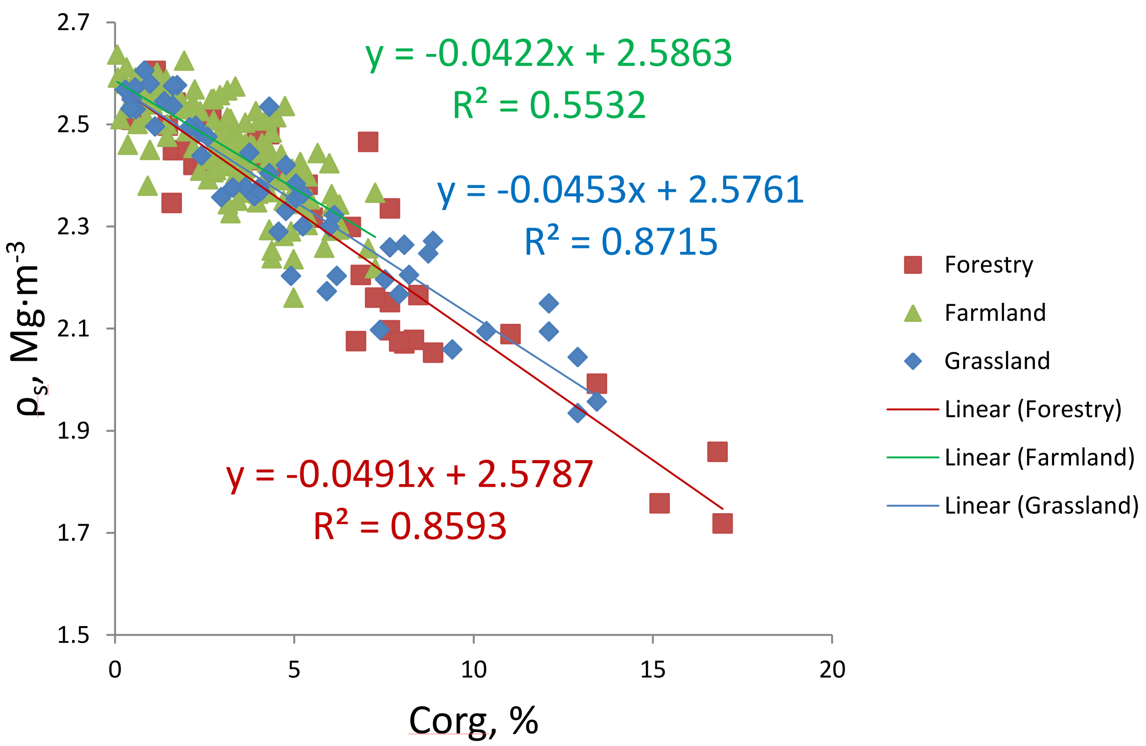

Figure 14. Linear regressions for bulk density as a function of SOC content under different land uses.

The above regression equations show that in all cases the mineral particle density is close to 2.58 (the intercept values), which is already lower than the the commonly assumed value of 2.65 (calculated density of quartz) used in Saxton and Rawls model. Mineral densities are usually different from calculated values due to imperfection of crystals. Furthermore, the ρ_s values decrease significantly with increasing carbon content. The rate of decrease also varies depending on the quality of organic material associated with different land uses (the dry density of wood is different from density of grass and maize residues). Subsequently, one could say that using measured particle density values may improve the quality of bulk density calculations from predicted porosity. The correlations coefficients are fair for forestry and grassland areas (r^2=0.87 and r^2=0.86 respectively). That is mainly due to the presence of samples with very high carbon content, which allow to define the trend more clearly. In cultivated areas the correlation coefficient is rather poor (r^2=0.55), which emphasized the effect of mineral heterogeneity in soils with lower organic matter concentrations.

3.2.3 Multiple regressions for porosity calculation from soil texture, carbon content and sample depth.

There is a close relation between bulk density and porosity in the soil being indirectly proportional. That means, while bulk density is increasing with depth, porosity is decreasing with it (Kizilkaya & Dengiz, 2010).

As porosity plays a main role in the calculation of different outcomes of the Saxton & Ralws model, it is important to break down the formulas applied as well as the accuracy and the statistic approach that Saxton & Rawls (2006) explained in their research. Although, the researchers used selected tension for estimating soil water content choosing 1500, 33 and 0 to 33 kPa, the correlation based on r^2 values is fairly high reaching 0.86 for 1500kPa (understandably so, because it’s directly related to mineral composition and amount of water layers on the mineral surfaces) and 0.63 for 33 kPa (which is more dependent on organisation of minerals into structural aggregates). Nevertheless, accuracy of the equations developed from the soil water content equation show less correlation especially the one which represents saturated moisture at 0 kPa, which is more uncertain due to aggregate slaking, strength of aggregates and pore continuity (Table 5).

One could assume that the numbers of samples taken from the field are independent from each other to make all the regression and to run the SPAW model. However, sampling was done making increments of 5, 10 or 25cm increments where in reality all the samples taken from one pit were related to each other, making them dependent variables within the profile subset. Content of sand, clay or organic matter cannot be independent throughout the profile due to constant interaction between all layers because of presence of micro fauna, macro fauna or weather conditions (Bruun at al., 2010).

Assuming that the samples are independent, they cannot be display using linear regression. This based on that single values could randomly agree, but without any statistical basis. However, using a Bland & Altman plot one could appreciate the distribution and the accuracy of method better than using correlations.

Preparation of the data was needed to carry out the scatter of Bland & Altman. Multiple regressions were done in the existing data with the purpose of compare the results with the existing model by Saxton & Rawls. During this study, it was decided to create two different multiple regressions, the first based on sand (S), clay (C) and organic matter (OM) and the second adding depth (Z) to the same components. The depth factor z was added knowing that porosity decreases in deeper layers due to higher pressure. Further, the results of Saxton & Rawls model were also plotted. Figure 15a, 15b and 16 represent both regression obtained from existing data taken in the field and Soil water characteristic model results In these cases the difference between measured and modelled values is evaluated in terms of averages and standard deviations..

Figure 15a and 15b show how the regressions tend to overestimate in the shallower layers and overestimate in the deeper layers. Here but also it is important to point out that the regressions are based on field values where mean was standardized to equal 0. Nevertheless, the variation is a fairly low reaching 10.93 and 10.92 respectively meaning that the introduction of an extra variable (depth) does not significantly reduce the error or estimation.

After, independent variables were created with the purpose of showing appropriate correlation between all parameters and validate the comparison between regressions and Saxton & Rawls model. Averages were made for each profile, namely, every profile ended up having a unique value of sand, clay and organic matter content.

a b

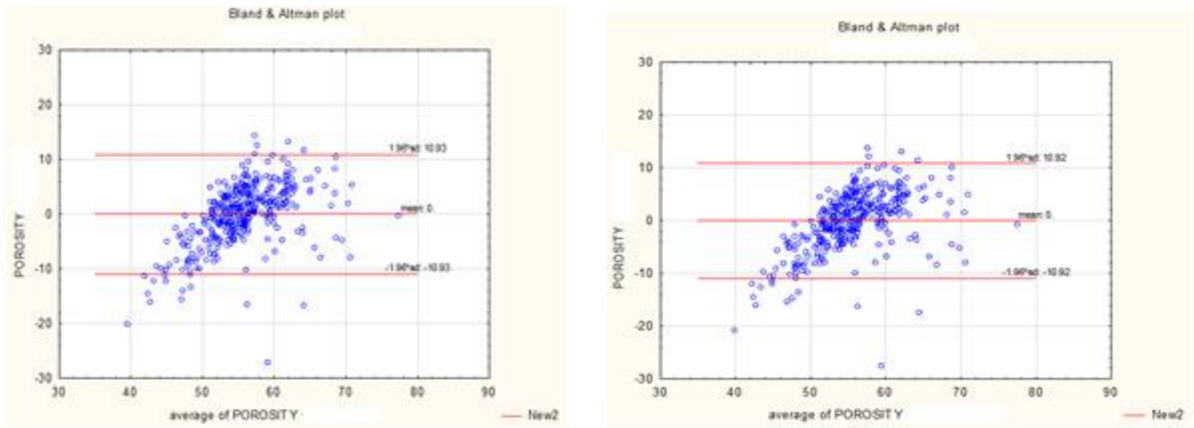

Figure 15. Plot of the multiple regression for porosity (%) prediction errors a) using S, C and OM as inputs and b) using S, C, OM and Z as inputs.

The results obtained from doing the average became independent variables from one another and an average of 400 values became in average 46 values which were used to approach the rest of the correlations.

The Addendum C shows correlations where every depth was analyzed and compared. The tendency of the two regressions and the model are fairly similar from the surface up to 50cm deep where the correlation with the field porosity is poor at the top value (0-5cm) and start increasing from 5 to 50cm. Nevertheless, both regressions and model present poor correlations between 50 and 100cm.

Figure 16 shows bigger deviations close to 20 and -20, but in the Soil water characteristic model the case is completely different because it tends to underestimate shallower values and overestimate deeper values. It proves that locally developed regressions have higher predictive value.

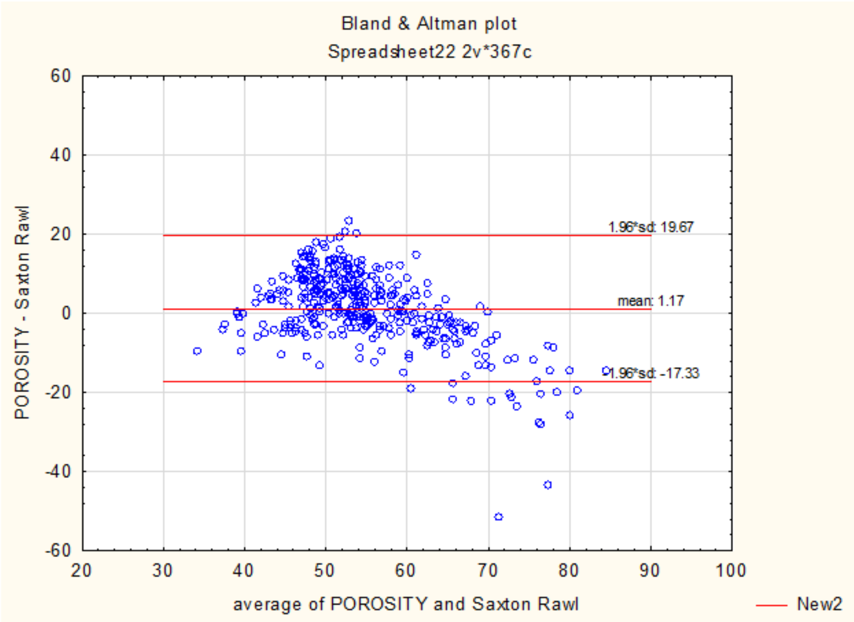

Figure 16. Saxton & Rawls approach for porosity (%) prediction error using sand, clay and organic matter content.

Independent values were compared, excluding values of the interval 75-100cm due to lower number of samples representing these depths. Linear regressions were created in order to compare predicted and measured porosity values averaged per soil profile.

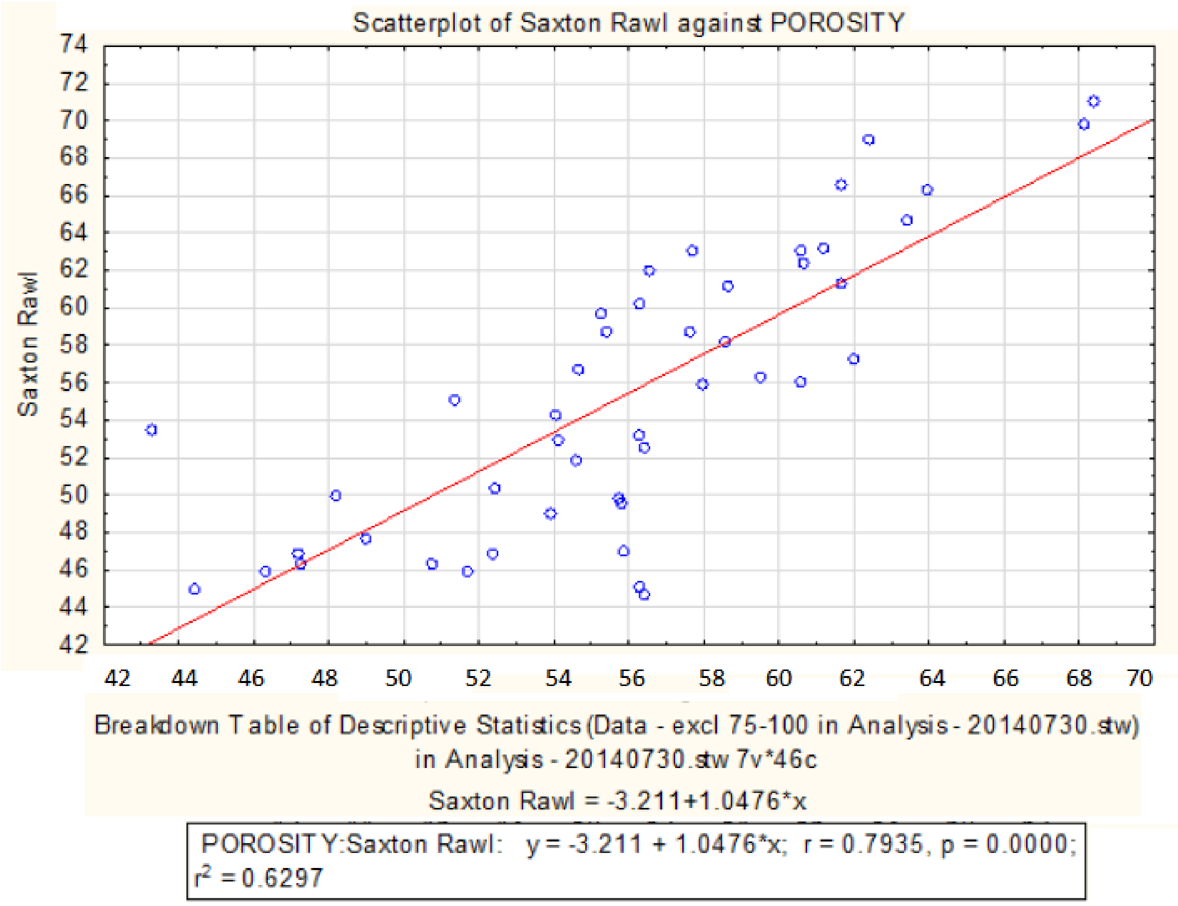

Figure 17 Porosity (%) prediction with Saxton & Rawls vs. measured porosity values.

On the other hand, Figure 18 shows one the proposed multiple regression and its correlation between field porosity and sand, clay and organic matter content. It demonstrates a better correlation than Saxton & Rawls model showing a fairly higher r^2 value of 0.71.

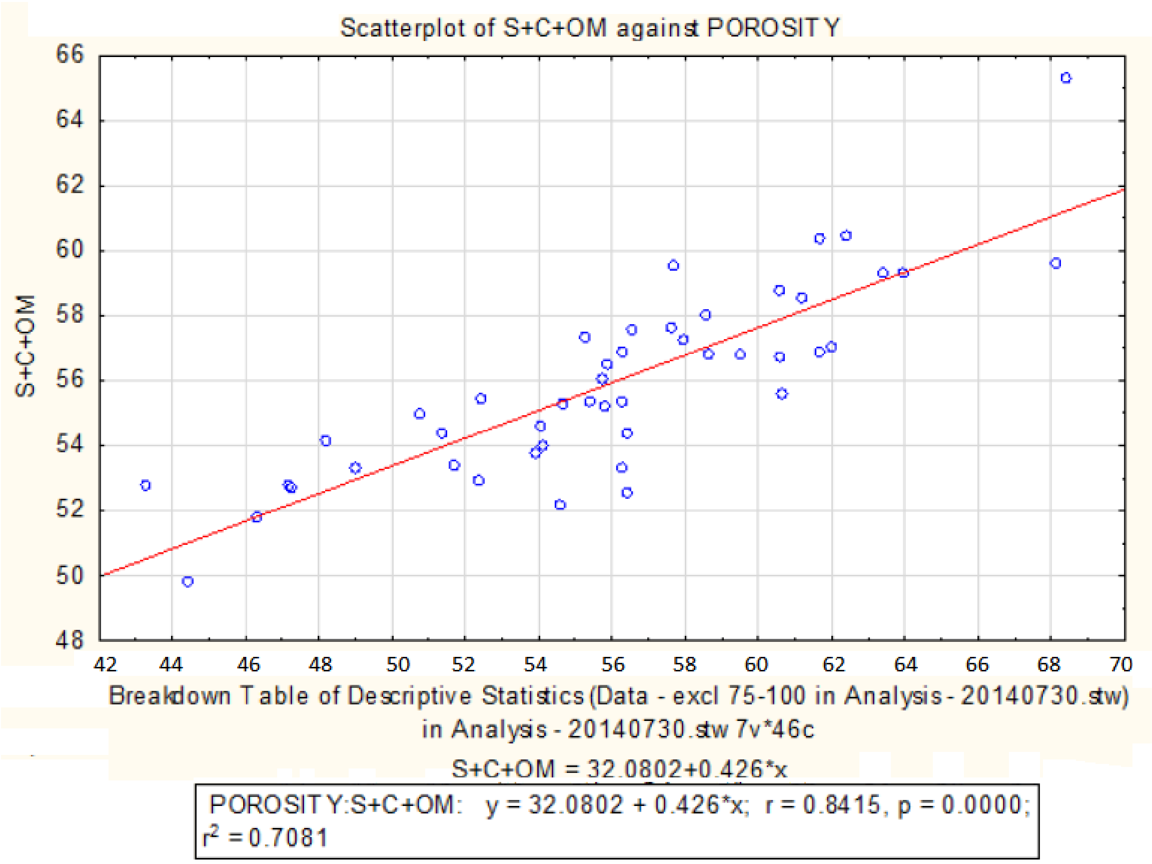

Figure 18. Multiple regression with S+C+OM paremeters against the measured porosity (%) values.

Although, introduction of z (sample depth) as factor did not significantly improve the error of estimate (Fig 15 a and b), the regression between predicted values using addition of z parameter is significantly better. The figure 19 shows the correlation coefficient reaching an r^2 of 0.84; this might means that actually depth plays a key role in predicting porosity independent of land uses or soil forms. Further, this improvement relies on the results obtained when every depth was analyzed which is shown in Addendum C.

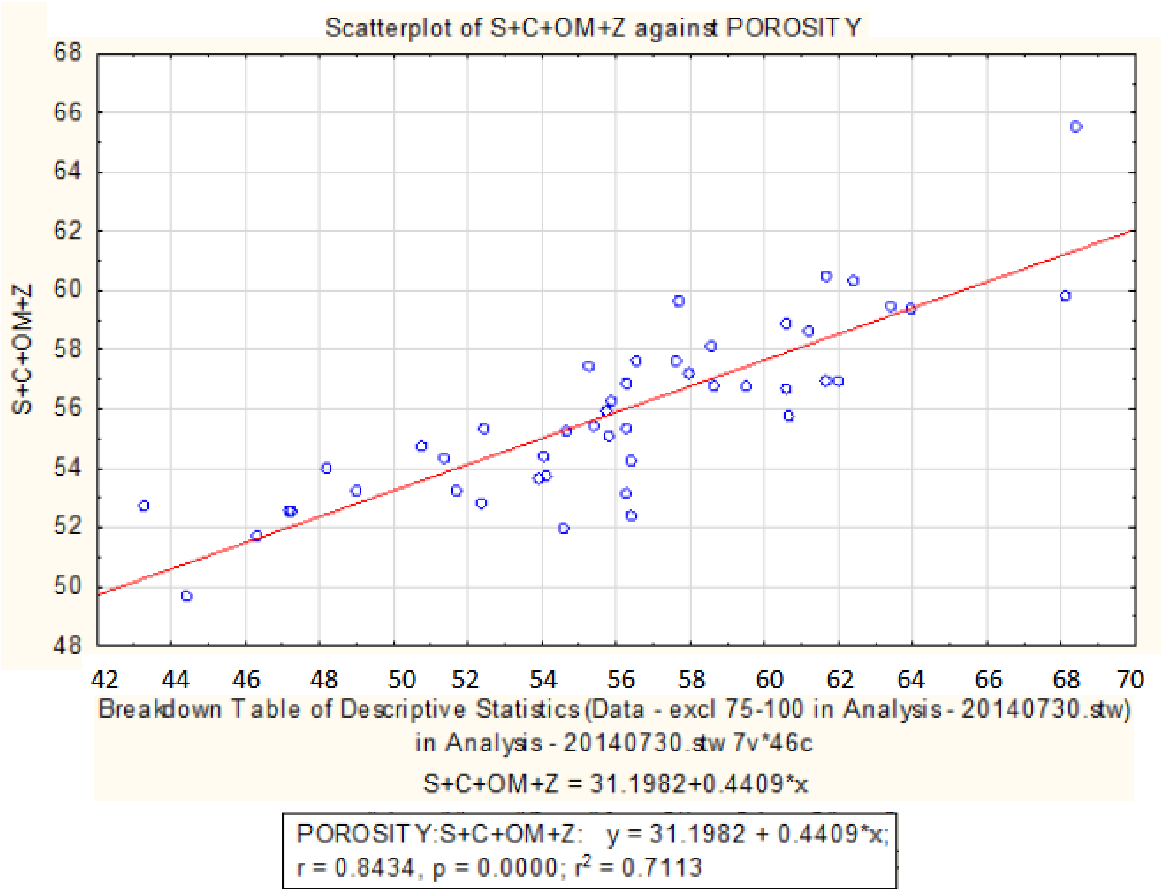

Figure 19. Multiple regression with S+C+OM parameters against the measured porosity (%) values.

Finally, new Bland & Altman plots were created with the averages of each profile following the tendency described when the entire dataset was used, but showing a better mean value for Saxton & Rawls model and better standard deviation for both regressions and model. Figure 18 shows the best regression which resulted to be the one including depth and Figure 21 shows the final plot for Saxton & Rawls model.

As one could expect the mean value in Figure 20 changed based on the use of the independent values and the standard deviation are much lower showing that even though the tendency of overestimating in shallower increments and underestimating deeper increments is still clear that the approach is more accurate and it has the correlation of the regression made in Figure 19 to prove it. Still the r^2=0.71 observed here may not be good enough for carbon audit purposes.

a *b*

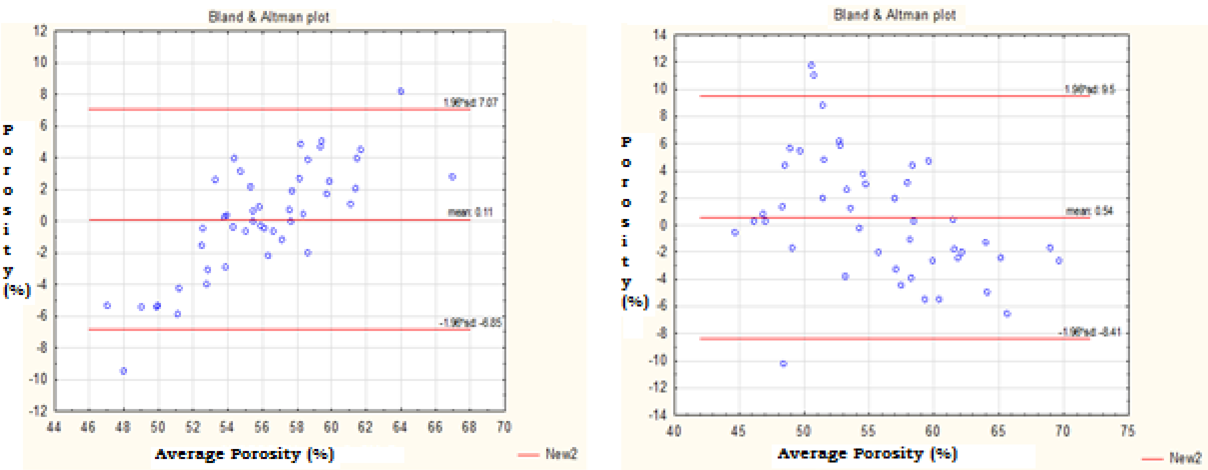

Figure 20. Bland & Altman plot for a) the multiple regression of profile-averaged porosity calculated from S, C, OM and Z parameters and b) for Saxton and Rawls model.

On the other hand, Figure 20 shows a remarkable improvement in diminishing standard deviation values and mean value in comparison to Figure 15. The aforesaid reaffirms that the breakdown of data is necessary to acknowledge the real correlations of data showing at the end that Saxton & Rawls approach based on soil water content still could be fairly accurate, but the inclusion of depth also appears as a factor to include in approaches to predict porosity.

The main problem of both locally-developed multiple regression and the Saxton and Rawls models is the poor prediction of bulk density in individual samples. The profile averages, which can be reasonably predicted with both approaches are not suitable for application in the calculation of the volumetric SOC content in the 0-5 cm layer.

From this section one can conclude that, although a locally-developed depth-adjusted multiple regression improves on porosity prediction of the Saxton and Rawls model, the improvement is not sufficiently high to justify development of new regressions using the same parameters or even adding the depth factor.

3.2.4 Improving bulk density predictions of Saxton and Rawls model by adjusting the particle density parameter.

Based on the assumption that the variables are independent of each other, even though they are dependent especially for organic matter content, the existence of a trend showed during the analyses of porosity allows approaching the analysis of bulk density differently and comparing the observed ρ_b values with those predicted by Saxton & Rawls model more freely.

The first step to prepare the data for the SPAW software was to obtain organic matter content based on organic carbon content results obtained from the samples taken in Mvoti valley. The factor of conversion was 1.724 considering the assumption that all kind of organic matter contains 58% of organic carbon (Howard, 1965).

Subsequently, the data was inserted into the SPAW software for each profile and every layer (see Addendum A). Two outcomes were analyzed after running the soil water characteristic model, the first one only supplying the values of texture required and the organic matter content calculated from the factor suggested by Howard (1965); and, the second one following the same procedure adding the experimental value of porosity calculated using the observed particle density values. Different land uses were modelled separately.

In case of farming as a land use, compaction factor DF was used to accommodate loosening of the topsoil by tillage. The factor used for the first 30cm of the profile was 0.9 based on the depth that the plough reaches becoming a loose soil specially before seeding. Then, from 30cm to 75cm 1.1 was set as a normal value of compaction associated with subsurface effects of agricultural machinery traffic, and 1.2 when the profiles reached 1m depth.

The three results of the model were combined in Excel sheets (Addendum D). Stratified averages (the same procedure as used for modelling volumetric carbon content) were calculated to compare the two approaches. The first dataset running on the model was obtained using clay, sand and the organic matter content calculated from organic carbon content. The second set used porosity valued adjusted to observed.

In forestry areas (Fig 21 and 22) one can see fitting of the linear trend line is smooth and the value of the r^2 is fairly high, reaching a value above 0.9, in this case Saxton & Rawls model has adapted to a rich dataset which contains 22 profiles between pits dug in eucalyptus and pines plantations. Soil water characteristic model based on texture have been found the most accurate among eight different models which use texture, bulk density and organic matter as parameters, but it needs to be calibrated depending on the geographical area and soil forms (Sung & Iba, 2010).

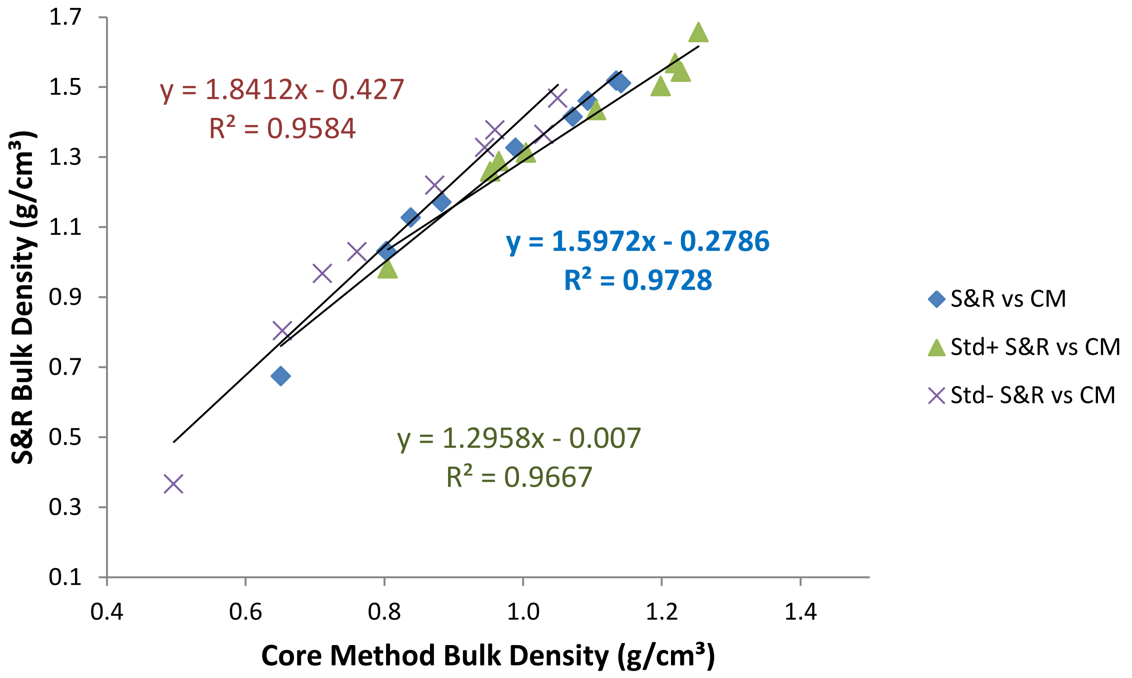

Figure 21. Correlation between S&R model with constant (2.65) particle density and observed values for forestry.

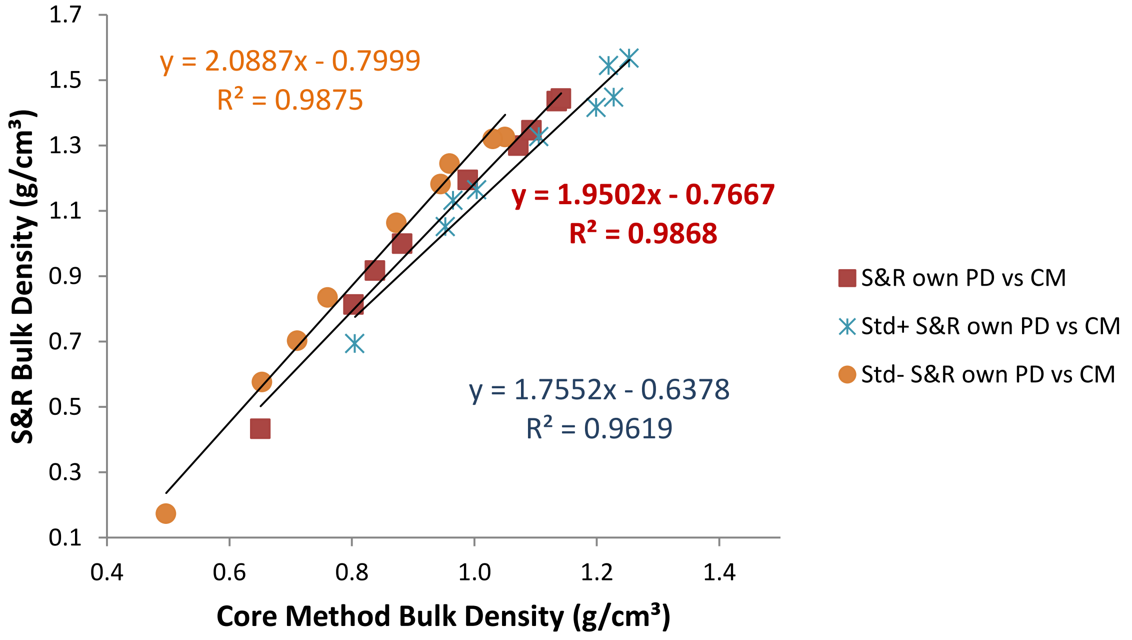

Figure 22. Correlation between S&R model adjusted by measured particle density and observed bulk density values for forestry.

The particle density was deemed necessary based on the considerations given in section 3.2.2. The results improved slightly (Figure 22) Even though, other authors have added corrections to incorporate compaction, gravel and salinity effects (K. Saxton & Willey, 2006), it would be important to include particle density as part of the input variables set.

On the other hand, grassland during the first analysis showed lower correlation than plantation forestry in general. Nevertheless, the tendency of improvement continues being present when the analysis is conducted using particle density measured using the pycnometer method (see Figures 23 and 24). The analysis was conducted with 7 different profiles located at different altitude.

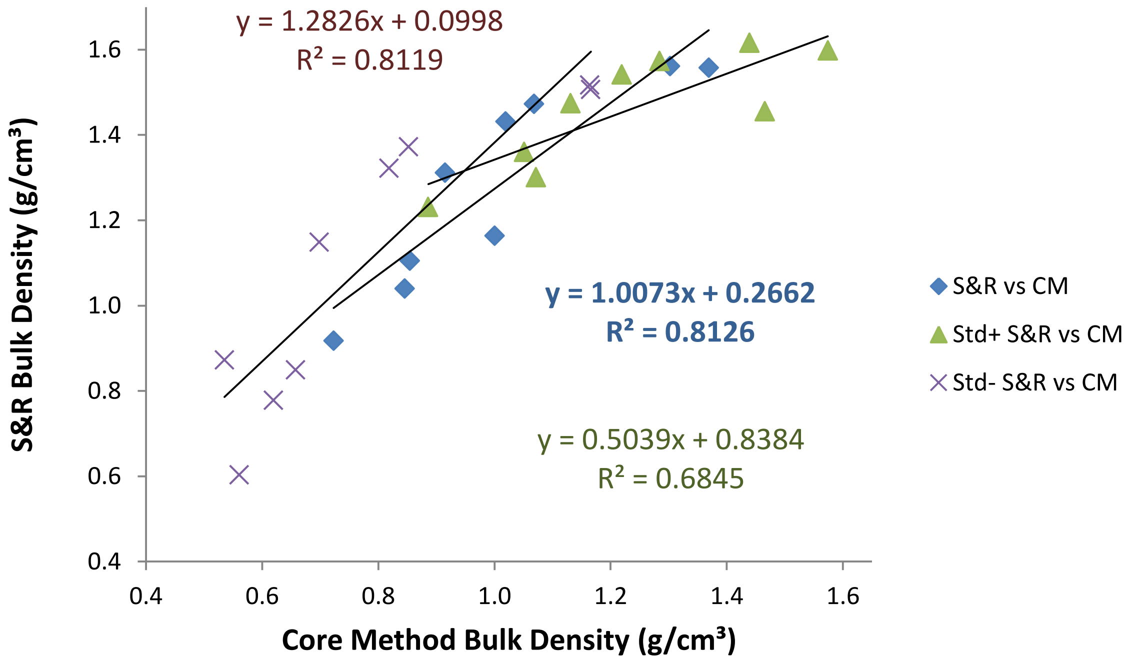

Figure 23. **Correlation between S&R model with constant (2.65) particle density and observed values for *grasslands.***

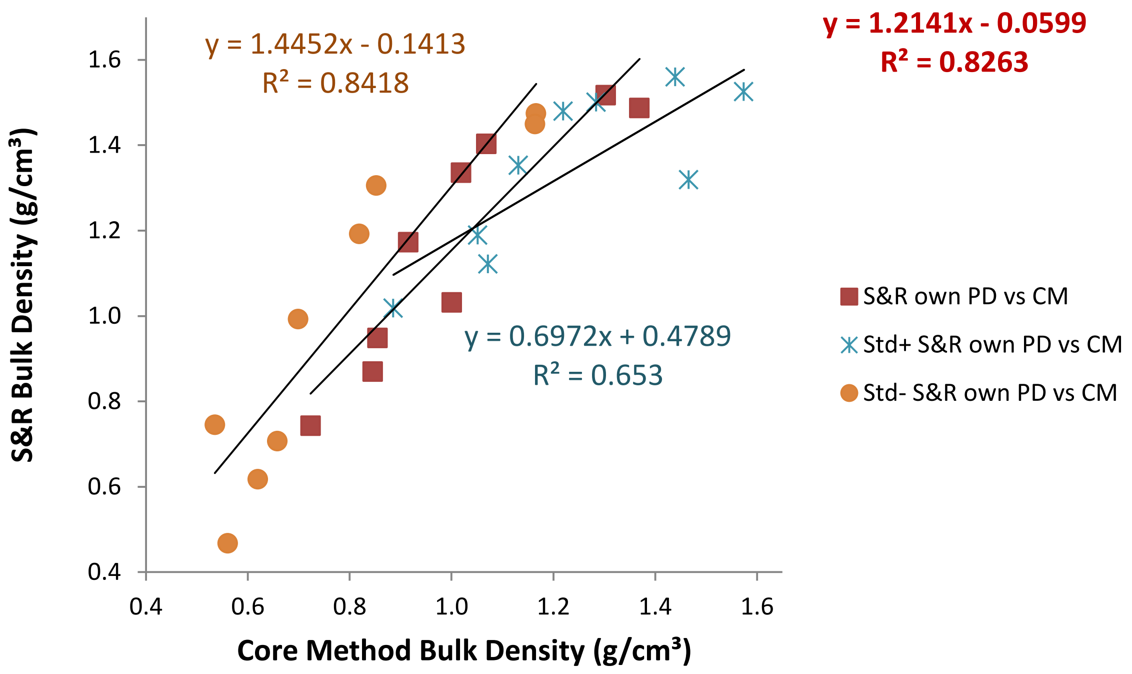

Figure 24. Correlation between S&R model adjusted by measured particle density and observed bulk density values for grasslands.

Finally, farming dataset was analyzed (see Figure 25 and 26). As one can see the correlation between the model and the real values is much lower than the one found in grasslands and forestry areas. Nevertheless, one could say that the correlation is sufficient due to many factors influencing farming lands. One of them is the process of ploughing which influences directly on the approach of the core method used during this research to calculate bulk density and also at least the first 30cm of each profile was disturbed, broken and mixed by the plough of 9 out of the 16 profiles categorized as farming land on this study. Furthermore, on the profiles were heavy weight tillage machineries were introduced for ploughing during the last decade the formation of a plough pan is common provoking a hard layer difficult to penetrate with the core and even with a shovel (Podder et al., 2012). This last point might also affect the field measurements taken in the field from 30-40cm deep. Nevertheless, the model offers an alternative for situations like the one described aforesaid, giving a density factor. Based on density factor different values were selected for each layer as it was explained before under this section.

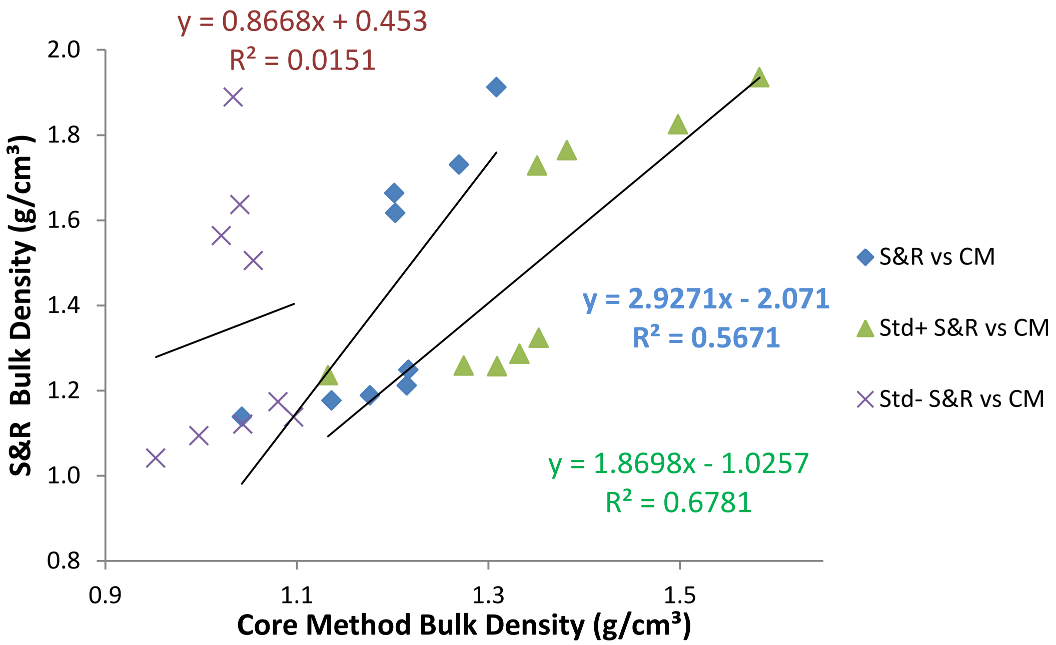

Figure 25. Correlation between S&R model with constant (2.65) particle density and observed values for croplands.

The complement between density factor and particle density taken from pycnometer method (Figure 26) modestly improved the final results (r^2=0.59).

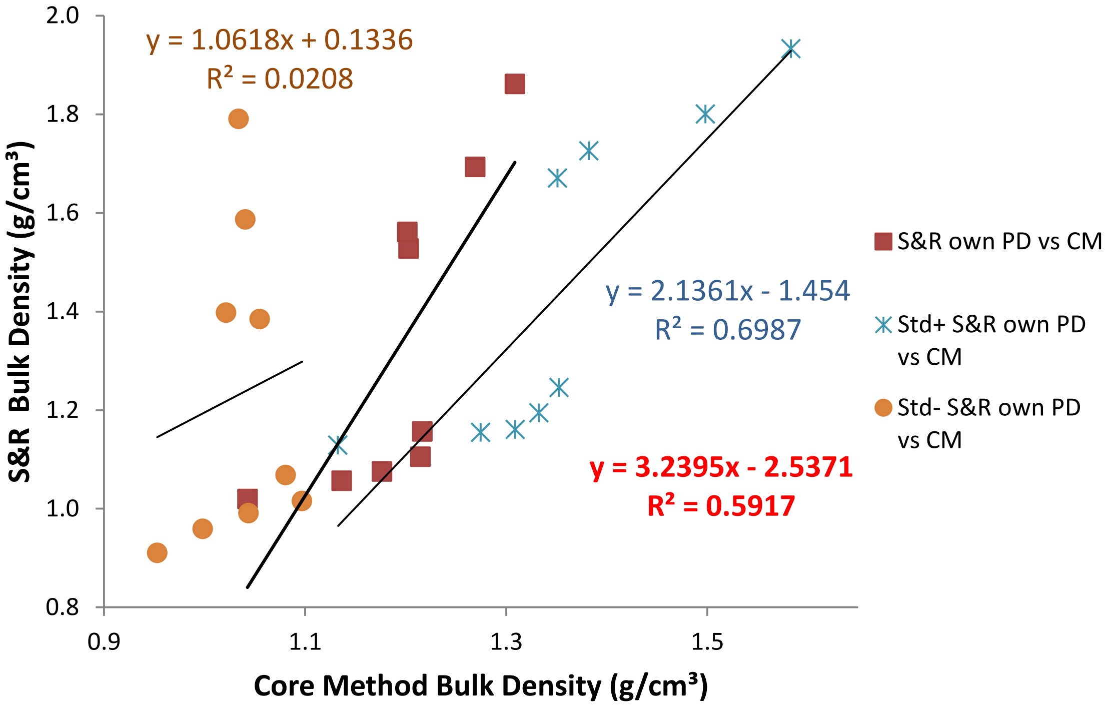

Figure 26. Correlation between S&R model adjusted by measured particle density and observed bulk density values for croplands.

The main drawback of the correlations presented in Figures 21-26 is that the correspondence between the observed and modelled values is not 1:1 as can be seen from all the correlation equations. All the equations include an intercept apart from the slope factor. It means that the results of Saxton and Rawls model predictions cannot be used directly, but require an additional transformation step with varying degree of accuracy for different land uses. Saying that one should keep in mind that the Saxton and Rawls equations were developed for particle size distribution data obtained by traditional pipette method, which may yield significantly different results from the laser beam particle size analyser used in this study. Soil preparation may also have had a significant impact on PSD analysis results, and subsequently their correspondence with Saxton and Rawls model outputs. Moreover, some of the top soils that were analyzed during this research had the estimated organic matter contents were higher than 7% which in cases of exceeding 15% gives either very low and unrealistic data or negative values in the SPAW model. That results directly from the exclusion of such values regression from development of the original equations (Reynolds et al., 2000).

Allen et al (2005) pointed out, although bulk density is an important parameter normally is not measured because it is a time-consuming method and based on the same reason it is not sampled unless the main focus of the research is to develop carbon stocks through a survey. Nevertheless, Saxton & Rawls model could to be a useful tool for predicting average bulk densities for large areas, e.g. regional or nation soil carbon surveys. At local level of our study catchment, the equations presented in Figures 21-26 may be used as “localisation” parameters for Saxton and Rawls model outputs requiring an additional calculation step.

Still, it seems that direct measurement of bulk density is the best possible solution for local soil carbon inventories and audit, particularly if only a one sample close to soil surface is required as suggested by exponential equations provided in section 3.2.1.

The main conclusions from this section may be formulated as following:

- Improvement in Saxton and Rawls model output is possible and necessary for soil samples with high SOM content using the particle density values adjusted for SOM content;
- “Localization” of Saxton and Rawls model through an additional calculation step using the linear regression developed here may be carried out for the Oxisols dominating the study catchment with high degree of accuracy for forestry and grassland areas, while predictions for croplands carry low accuracy;
- A direct measurement of bulk density is essential, not only preferable to predictions from texture and SOM content for catchment/farm level soil carbon accounting;
- Bulk density predictions may be successfully used for regional/national inventories.

Example: application of the exponential vertical carbon distribution model to soil carbon mapping in the study area.

The example of application given below was developed together with L. Wiese and A. Rozanov, the 3D GIS work was performed by A. Boshoff and presented by L. Wiese at the 20th International Congress in Korea (2014). Although, the maps provided below are the result of group work, it is essential to reproduce them in this thesis as an example and explanation for application of the models developed in section 3.1 of this document.

Application of the exponential model was carried out using QGIS in one of the Mondi forest plantations. The area was selected based on the detailed soil data provided by Mondi for the study, as well as on the number of surface soil samples taken in the area as part of this study (Figure 27).

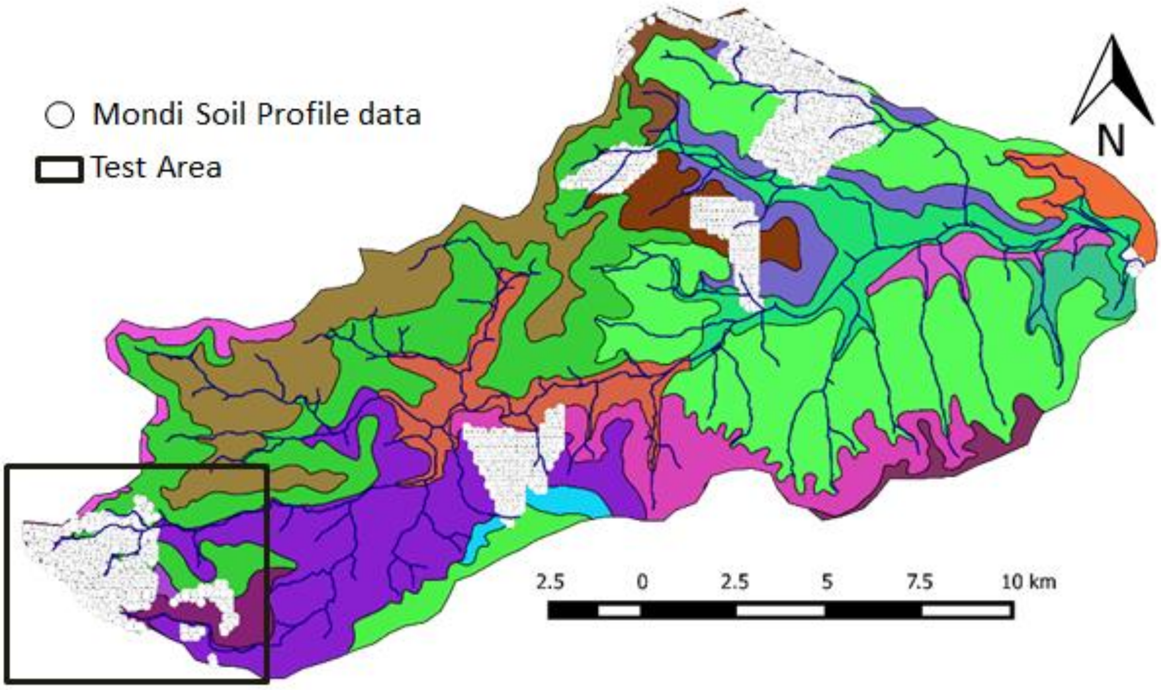

Figure 27. Interpolation area corresponding to the Mondi dataset (1:10000)(Wiese et al., 2014).

Based on the hypothesis that the exponential functions for vertical SOC distribution may be used to predict vertical volumetric carbon content down to 1m or limiting depth layer (e.g hard rock) using only a surface soil sample, more than 100 new points were randomly sampled throughout the catchment, taking only surface core samples at 0-5cm depth (Figure 28). Each of the new points was sampled in triplicate to reduce sampling error. Bulk density of the samples were determined by the author, while the SOC determination was conducted by L.Wiese using near-infrared spectroscopy (Wiese et al. 2014).

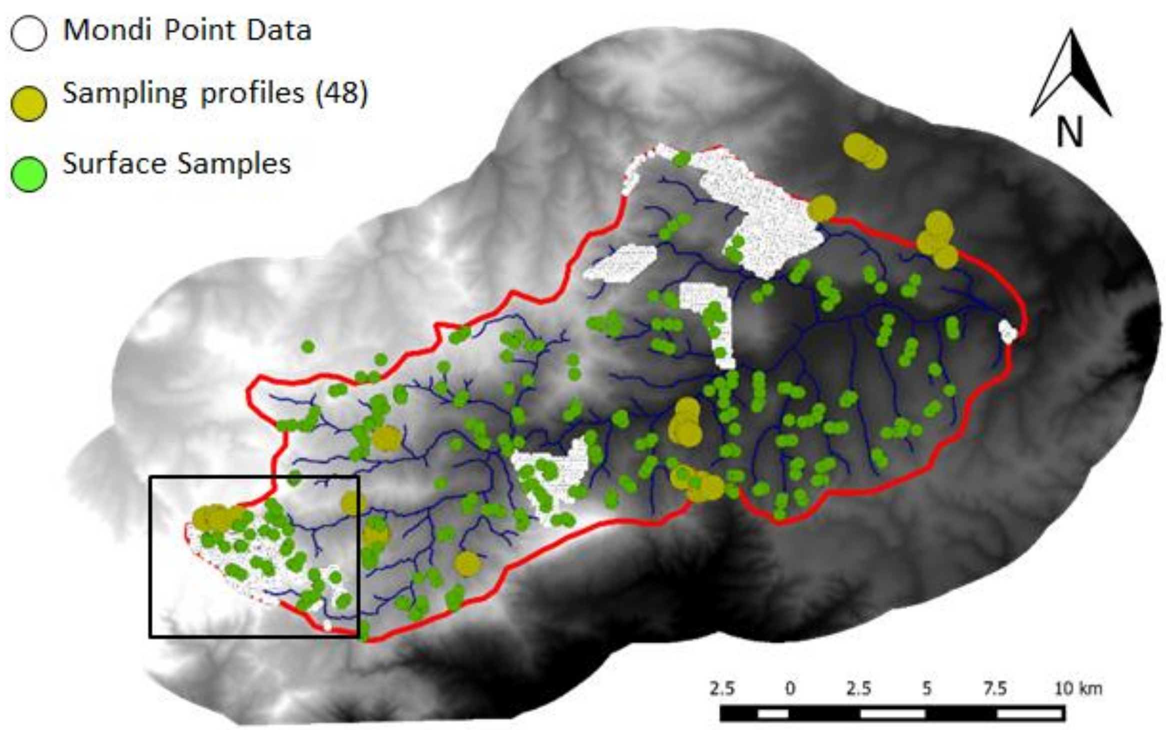

Figure 28. Points of vertical distribution (profile) and surface sampling (Wiese et al., 2014).

In this case, thanks to the Mondi Forests, which provided the results of soil survey in their plantation area, it was possible to isolate the shallow soils with effective rooting depth less than one meter through co-kriging interpolation of soil survey results.

In order to populate the integral equation (Equation 5), a raster map was created for each variable QGIS, namely volumetric carbon content at the soil surface (Cv), the slope of the exponential function (l), as well as the soil depth (z) (taken as effective rooting depth). All parameters were co-krigged with curvature; slope and elevation data obtained from a 20m digital elevation model (see Figure 28).

$$\boxed{\int_0^z Cv \cdot e^{-lz}\,dz = \frac{Cv}{l} \cdot \left(1 - e^{-lz}\right)}$$

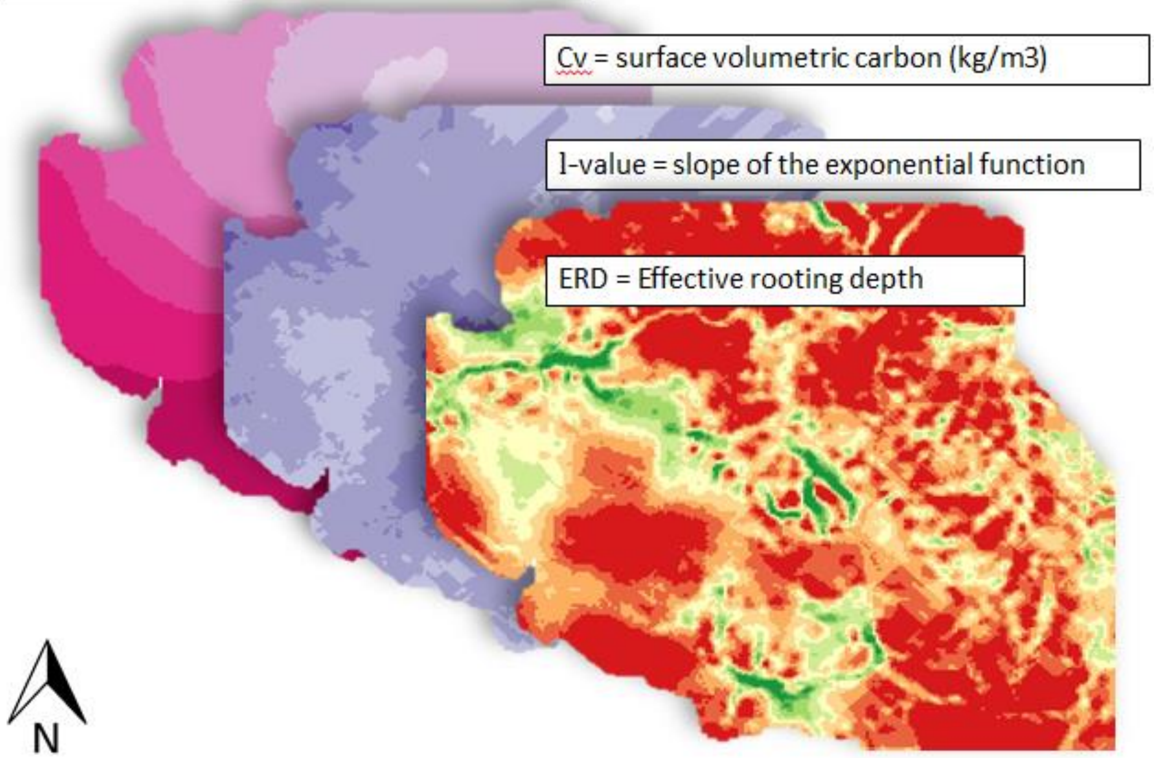

Figure 29.**Overlay of the three integration components: volumetric carbon content (Cv) at the surface, slope of the exponential function and the effective rooting depth (Wiese et al., 2014).**

As Figure 29 shows, one of the most important applications of the model using QGIS is the the raster calculation of the cumulative soil organic carbon stocks up to 1m depth. Although, the model has a local application, it is able to give a reliable approximation of real values of carbon content of one specific valley, provided the model is calibrated with local values taken from the same area or with similar characteristics, in terms of soil forms, climate or land uses.

Figure 30 displays cumulative SOC content up to effective rooting depth (maximum depth of 1m) which could be determinant for decision making on a farm or on a forestry plantation area alike. On the other hand, Figure 31 represents how soil organic carbon stocks are distributed across the test area, overlain with land uses indicating that there is a variation on the distribution of SOC content within different land uses (in this case only forestry and grasslands, since there is no cultivation in this part of the catchment).

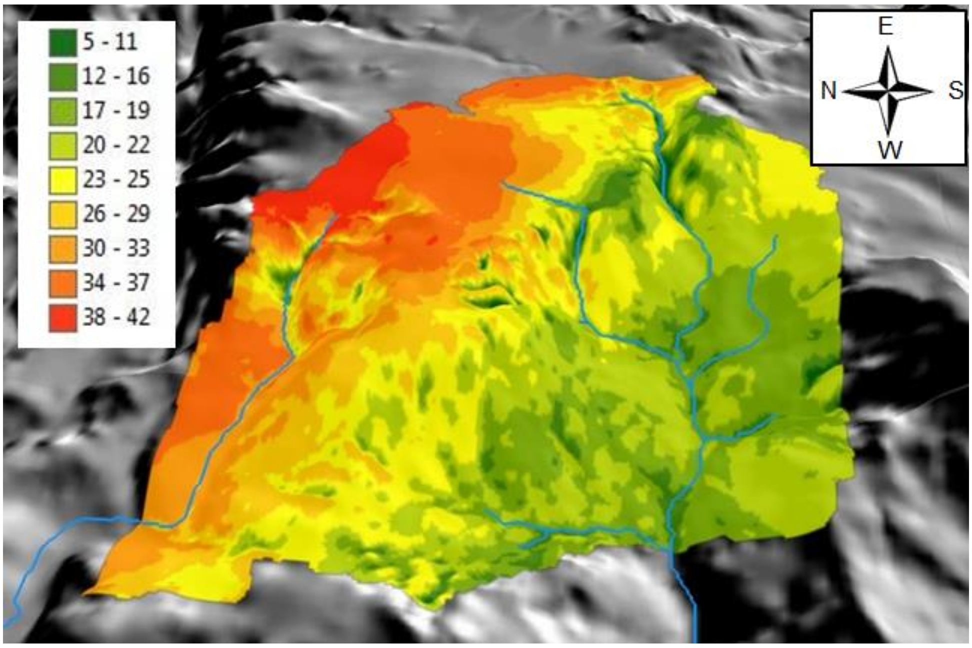

Figure 30. Representation of soil carbon stocks (kg/m^2) based on the effective rooting depth (Wiese et al., 2014)

The visualization of soil carbon stocks distribution (Fig. 30) gives a good indication that high carbon stocks are associated with high-altitude plateau, while the rocky steep slopes of the valleys store relatively little carbon. It should be noted again, though, that the wetlands in the valleys were excluded from this model and substantial carbon deposits may be found associated with riparian zones and wetlands in the area.

4. CONCLUSIONS

Calculating the integral of the exponential vertical SOC distribution function using of soil carbon content at the soil surface (using Walkley & Black analysis) and slope of the exponential function gives reliable and relatively accurate (quantified by standard deviations) results to assess cumulative carbon stocks for either different kind of land uses such as, forestry, farming and grasslands with defined confidence limits for the Mvoti river valley, located in KwaZulu-Natal (KZN) province. The method was proven to be effective for pre-determined depth increments and not using separate layers (horizons) of the profile based on its colours and other properties. Furthermore, the use of this method can make soil carbon accounting more time and cost-efficient. Moreover, the model could improve future soil carbon surveys, assessment and audit carbon an easier, cheaper and reliable task.

The main conclusions from this section may be formulated as following:

- Exponential decline model of normalized volumetric SOM distribution adequately describes the average observed distributions with depth.
- A single observation of SOM content and soil bulk density conducted in triplicate close to the soil surface is sufficient to estimate the SOM stock down to the depth of 1m.
- The error of estimation on average is under 10% of the value for grasslands and croplands, while in forestry areas, due to high variation from average the error increases to 20%.

Although, the methodology was successfully tested in the study area it would be appropriate to test it in additional areas with different rainfall, altitude, soil forms and other land uses. Independent validation of the proposed models is also necessary, but is subject to availability of funding to create a validation data set.

Furthermore, representation of the data given for the model can be successfully represented by GIS making the decision support more reliable for land users and parties involved in soil carbon inventories.

Regarding the use of soil texture data to predict bulk density values in the study catchment, the results are quite disappointing. It may be explained primarily by the nature of the soils – predominantly Oxisols with very high carbon content, very low bulk density values at the surface and high porosity throughout the profile.

The main problem of both locally-developed multiple regression and the Saxton and Rawls models is the poor prediction of bulk density in individual samples. The profile averages, which can be reasonably predicted with both approaches, are not suitable for application in the calculation of the volumetric SOC content in the 0-5 cm layer.

From this section one can conclude that,

- Saxton and Rawls model predictions are only slightly inferior to locally developed multiple regression models using the same parameters and similar multiple regression models including the sampling depth as a factor;
- Improvement in Saxton and Rawls model output is possible and necessary for soil samples with high SOM content using the particle density values adjusted for SOM content;
- "Localization" of Saxton and Rawls model through an additional calculation step using the linear regression developed here may be carried out for the Oxisols dominating the study catchment with high degree of accuracy for forestry and grassland areas, while predictions for croplands carry low accuracy;
- A direct measurement of bulk density is essential, not only preferable to predictions from texture and SOM content for catchment/farm level soil carbon accounting;
- Bulk density predictions may be successfully used for regional/national inventories.

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ADDENDA

ADDENDUM A. SOIL CLASSIFICATION, BULK DENSITY AND SOC CONTENT PER PROFILE

Profile 1

A-1.1: General information of profile 1

South African Classification	*Ia1200*
USDA Classification	Humic Rhodic Haplustox
Location (GPS coordinates)	*S29.23147° E030.32460°*
Altitude (m)	*1514*
Land Use	*Plantation Forestry*

A-1.2: Description and comments of profile 1.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.59	8.8	• Humic A from 0-30cm • Horizon B thicker than 30cm • *Pinus patula*
	5-10cm	0.68	6.4	
	10-15cm	0.71	4.7	
	15-20cm	0.71	5.2	
	20-30cm	0.72	4.5	
	30-40cm	1.08	1.3	
	40-50cm	0.98	1.2	

Profile 2

A-2.1: General information of profile 2

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.23101° E030.33683°*
Altitude (m)	*1463*
Land Use	*Natural Forest*

A-2.2: Description and comments of profile 1.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.61	7.4	• Humic A from 0-33cm • Lithocutanic B > 33cm • Presence of rocks • Native species
	5-10cm	0.66	4.5	
	10-15cm	0.76	4.9	
	15-20cm	0.81	3.7	
	20-30cm	0.97	4.1	
	30-40cm	1.14	2.1	

Profile 3

A-3.1: General information of profile 3

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.23743° E030.39012°*
Altitude (m)	*1228*
Land Use	*Plantation Forestry*

A-3.2: Description and comments of profile 3.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.73	4.8	• Humic A 0-27cm • Neocutanic A/B transition 27-40cm • Lithocutanic B > 40cm • *Pinus patula*
	5-10cm	0.80	3.9	
	10-15cm	0.79	4.9	
	15-20cm	0.82	4.5	
	20-30cm	0.99	1.4	
	30-40cm	0.98	1.6	
	40-50cm	1.01	0.9	

Profile 4

A-4.1: General information of profile 4.

South African Classification	*Kp1200*
USDA Classification	Humic Haplustox
Location (GPS coordinates)	*S29.23731° E030.38881°*
Altitude (m)	*1210*
Land Use	*Plantation Forestry*

A-4.2: Description and comments of profile 4.

Profile Picture	Sampling Depth	Bulk Density (g/cm^3)	Carbon Content (%)	Comments
	0-5cm	0.43	28.0*	• 1m deep soil looks red with yellow mottles coming from weathering shale. • Harvested *Pinus patula*, recently planted with *Eucalyptus sp.* • Carbon content on sampling depth 0-5 might be contaminated with litter on top. It was left out of the model.
	5-10cm	0.76	7.8	
	10-15cm	0.84	4.6	
	15-20cm	0.85	4.5	
	20-30cm	0.94	3.2	
	30-40cm	1.02	1.7	
	40-50cm	1.04	0.9	
	50-75cm	1.10	0.9	

Profile 5

A-5.1: General information of profile 5.

South African Classification	*Ia1100*
USDA Classification	Humic Rhodic Haplustox
Location (GPS coordinates)	*S29.23764° E030.38889°*
Altitude (m)	*1223*
Land Use	*Plantation Forestry*

A-5.2: Description and comments of profile 5.

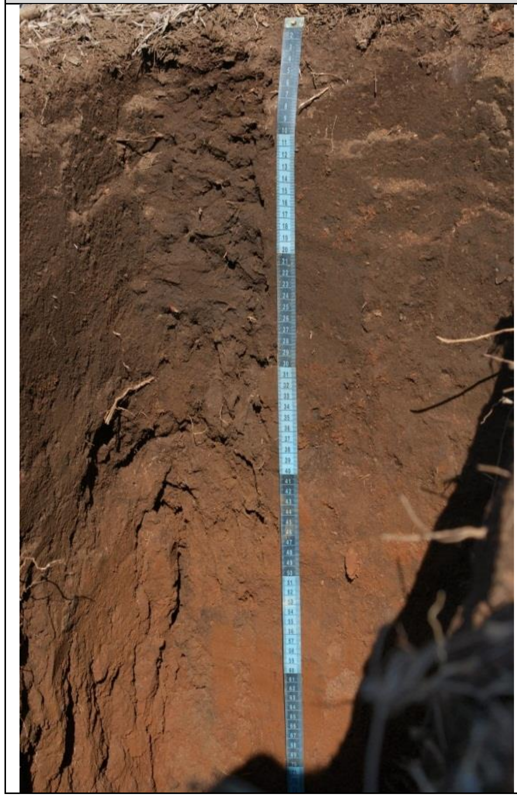
Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.70	9.8	• Sign of dolerite at 1m depth. • Harvested *Pinus patula*, recently planted with *Eucalyptus sp.*
	5-10cm	0.79	4.2	
	10-15cm	0.83	4.1	
	15-20cm	0.93	3.8	
	20-30cm	0.93	2.6	
	30-40cm	0.85	2.3	
	40-50cm	1.01	2.5	
	50-75cm	1.17	0.7	
	75-100cm	1.10	3.4	

Profile 6

A-6.1: General information of profile 6

South African Classification	*Ia1200*
USDA Classification	Humic Rhodic Haplustox
Location (GPS coordinates)	*S29.23829° E030.38847°*
Altitude (m)	*1222*
Land Use	*Plantation Forestry*

A-6.1: Description and comments of profile 6.

<table>
<tr><th>Profile Picture</th><th>Sampling Depth</th><th>Bulk Density (g/cm³)</th><th>Carbon Content (%)</th><th>Comments</th></tr>
<tr><td rowspan="9"></td><td>0-5cm</td><td>0.64</td><td>9.8</td><td rowspan="9">Sequence of horizons: Humic A, A/B, red apedal B and Lithocutanic B (Soft).
Harvested Pinus patula, recently planted with Eucalyptus sp.
Crest of the hill</td></tr>
<tr><td>5-10cm</td><td>0.92</td><td>4.0</td></tr>
<tr><td>10-15cm</td><td>0.97</td><td>3.0</td></tr>
<tr><td>15-20cm</td><td>0.94</td><td>3.1</td></tr>
<tr><td>20-30cm</td><td>0.94</td><td>2.3</td></tr>
<tr><td>30-40cm</td><td>1.02</td><td>1.2</td></tr>
<tr><td>40-50cm</td><td>1.03</td><td>1.0</td></tr>
<tr><td>50-75cm</td><td>1.16</td><td>0.3</td></tr>
<tr><td>75-100cm</td><td>1.21</td><td>0.3</td></tr>
</table>

Profile 7

A-7.1: General information of profile 7.

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.23685° E030.38955°*
Altitude (m)	*1234*
Land Use	*Plantation Forestry*

A-7.2: Description and comments of profile 7.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.62	5.0	• 3 years old *Eucalyptus sp.*, previously *Pinus patula.*
	5-10cm	1.02	2.4	
	10-15cm	1.01	1.8	
	15-20cm	1.16	1.3	
	20-30cm	1.27	0.8	
	30-40cm	1.35	0.5	
	40-50cm	1.17	0.6	

Profile 8

A-8.1: General information of profile 8.

South African Classification	*Ka1000*
USDA Classification	Typic Endoaquent
Location (GPS coordinates)	*S29.23652° E030.38925*
Altitude (m)	*1205*
Land Use	*Grassland*

A-8.2: Description and comments of profile 8.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.90	3.4	• Orthic A over a G-horizon. • Could be classified as a wetland.
	5-10cm	1.15	2.7	
	10-15cm	1.09	2.3	
	15-20cm	1.15	2.1	
	20-30cm	1.02	1.7	
	30-40cm	1.16	1.4	
	40-50cm	1.16	0.8	

Profile 9

A-9.1: General information of profile 9.

South African Classification	*Ka1000*
USDA Classification	Typic Endoaquent
Location (GPS coordinates)	*S29.23659° E030.38925°*
Altitude (m)	*1207*
Land Use	*Wetland*

A-9.2: Description and comments of profile 9.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
				• Profile not taking into account for the averages used on the research due to lack of information and difficulty of sampling. • Orthic A over a G-Horizon. • Water-table appears after 20cm deep.
	A-Horizon	1.07	6.1	
	G- Horizon	0.77	1.9	

Profile 10

A-10.1: General information of profile 10.

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.20098° E030.39375°*
Altitude (m)	*1286*
Land Use	Grassland

A-10.2: Description and comments of profile 10.

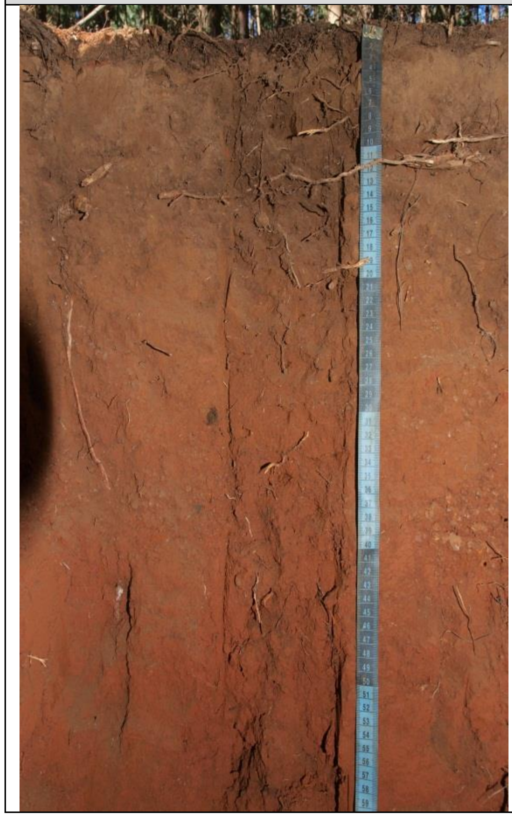
Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.75	5.5	• Humic A from 0-15cm • Lithocutanic rock from 15 to deeper layers.
	5-10cm	0.87	4.6	
	10-15cm	0.81	4.7	
	15-20cm	1.92	2.5	

Profile 11

A-11.1: General information of profile 11.

South African Classification	*Kp1200*
USDA Classification	Humic Haplustox
Location (GPS coordinates)	*S29.20122° E030.39375°*
Altitude (m)	*1286*
Land Use	Plantation Forestry

A-11.2: Description and comments of profile 11.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.50	10.5	• Humic A follows by a yellow apedal B. • Red apedal B appears on a red color with yellow mottles from dolerite around 110cm deep. • *Pinus patula.*
	5-10cm	0.80	2.9	
	10-15cm	0.83	3.2	
	15-20cm	0.88	2.7	
	20-30cm	0.99	1.7	
	30-40cm	1.21	1.1	
	40-50cm	1.06	0.7	
	50-75cm	1.07	0.8	
	75-100cm	0.95	0.4	

Profile 12

A-12.1: General information of profile 12.

South African Classification	*Ia1200*
USDA Classification	Humic Rhodic Haplustox
Location (GPS coordinates)	*S29.20088° E030.39218°*
Altitude (m)	*1256*
Land Use	Grassland

A-12.2: Description and comments of profile 12.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.74	4.3	• Humic A • Red apedal B • 100cm deep yellow fragments are seen, possibly from dolerite. • Large boulders next to the area where the profile is located.
	5-10cm	0.89	3.6	
	10-15cm	0.98	2.9	
	15-20cm	1.03	2.3	
	20-30cm	1.04	1.4	
	30-40cm	1.17	0.9	
	40-50cm	1.18	0.7	
	50-75cm	1.26	0.6	
	75-100cm	1.22	0.3	

Profile 13

A-13.1: General information of profile 13

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.22556° E030.39218°*
Altitude (m)	*1289*
Land Use	Natural Forest

A-13.2: Description and comments of profile 13

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.90	5.6	• Profile not used for the final averages on Forestry due to different qualities in compare to plantation forestry. • Big rocks under 40cm. • Humic A and Lithocutanic B.
	5-10cm	0.97	4.5	
	10-15cm	0.86	3.1	
	15-20cm	0.93	2.5	
	20-30cm	1.10	2.7	
	30-40cm	1.17	1.3	

Profile 14

A-14.1: General information of profile 14.

South African Classification	*Kp1100*
USDA Classification	Humic Haplustox
Location (GPS coordinates)	*S29.23062° E030.32897°*
Altitude (m)	*1490*
Land Use	Plantation Forestry

A-14.2: Description and comments of profile 14.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.35	12.5	• Humic A • Yellow-brown apedal B • Red apedal B • *Pinus patula*
	5-10cm	0.49	9.2	
	10-15cm	0.57	8.6	
	15-20cm	0.67	6.0	
	20-30cm	0.85	1.5	
	30-40cm	0.94	2.1	
	40-50cm	0.94	1.7	
	50-75cm	1.21	0.7	
	75-100cm	1.23	0.1	

Profile 15

A-15.1: General information of profile 15.

South African Classification	*Ch1200*
USDA Classification	Typic Epiaquent
Location (GPS coordinates)	*S29.23121° E030.32965*
Altitude (m)	*1496*
Land Use	Wetland

A-15.2: Description and comments of profile 15.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.45	6.240	• Profile not considered for the averages of grassland in the research. Considered another land type, not enough of them to model. • G over an organic A.
	5-10cm	0.70	4.990	
	10-15cm	0.65	8.500	
	15-20cm	0.44	12.480	
	20-30cm	0.37	12.480	
	30-40cm	-	-	
	40-50cm	0.74	-	

Profile 16

A-16.1: General information of profile 16.

South African Classification	*Kp1100*
USDA Classification	Humic Haplustox
Location (GPS coordinates)	*S29.23065° E030.32930°*
Altitude (m)	*1695*
Land Use	Grassland

A-16.2: Description and comments of profile 16.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.53	7.5	• Humic A from 0-15cm. • Yellow-Brown apedal B • Red Apedal B > 45cm.
	5-10cm	0.58	7.8	
	10-15cm	0.64	7.0	
	15-20cm	0.56	7.0	
	20-30cm	0.66	4.4	
	30-40cm	0.79	2.9	
	40-50cm	0.80	2.5	
	50-75cm	1.19	0.2	

Profile 17

A-17.1: General information of profile 17.

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.23232° E030.33017°*
Altitude (m)	*1516*
Land Use	Plantation Forestry

A-17.2: Description and comments of profile 17.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.51	11.5	• *Pinus patula.* • Humic A follows by Lithocutanic B.
	5-10cm	0.53	8.9	
	10-15cm	0.54	8.4	
	15-20cm	0.64	5.1	
	20-30cm	0.87	3.3	
	30-40cm	N/A	0.4	
	40-50cm	1.02	1.0	
	50-75cm	1.21	0.5	

Profile 18

A-18.1: General information of profile 18.

South African Classification	*Ma1200*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.09442° E030.57683°*
Altitude (m)	*1047*
Land Use	Farming

A-18.2: Description and comments of profile 18.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.97	2.1	• Harvested Maize • Conventional Tillage
	5-10cm	1.06	2.0	
	10-15cm	0.97	1.9	
	15-20cm	1.33	1.8	
	20-30cm	1.22	1.9	
	30-40cm	1.14	1.7	
	40-50cm	1.27	1.7	
	50-75cm	1.20	0.6	
	75-100cm	1.33	0.2	

Profile 19

A-19.1: General information of profile 19.

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.091823° E030.573022°*
Altitude (m)	*1026*
Land Use	Farming

A-19.2: Description and comments of profile 19.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.13	2.9	• Harvested Maize • Conventional Tillage • NES = Not enough sample.
	5-10cm	1.19	3.3	
	10-15cm	1.22	2.7	
	15-20cm	1.24	2.9	
	20-30cm	1.32	2.0	
	30-40cm	1.39	NES	
	40-50cm	1.19	NES	
	50-75cm	1.48	0.2	

Profile 20

A-20.1: General information of profile 20.

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.0906° E030.571048°*
Altitude (m)	*1016*
Land Use	*Farming*

A-20.2: Description and comments of profile 20.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.16	2.1	• Harvested maize • Conventional Tillage • Parental material reaching 50cm depth.
	5-10cm	1.09	3.1	
	10-15cm	1.12	2.9	
	15-20cm	1.22	2.7	
	20-30cm	1.30	0.5	
	30-40cm	1.46	0.5	
	40-50cm	1.71	0.2	

Profile 21

A-21.1: General information of profile 21.

South African Classification	*Du1200*
USDA Classification	Typic fluvent
Location (GPS coordinates)	*S29.090131 E030.56994*
Altitude (m)	*999*
Land Use	*Farming*

A-21.2: Description and comments of profile 21.

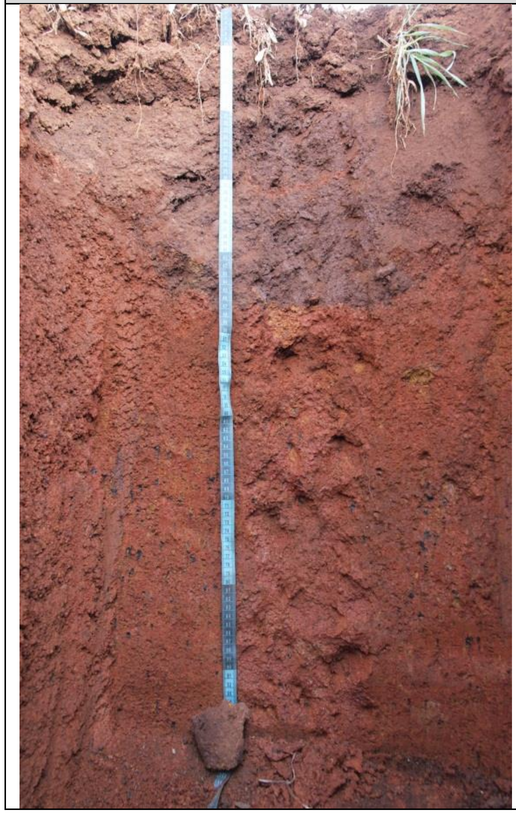
Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.98	2.9	• Harvested maize • Humic A < 35cm • Stratified alluvium from 71-115cm. • G-Horizon > 115cm • Conventional Tillage
	5-10cm	1.21	2.5	
	10-15cm	1.36	2.5	
	15-20cm	1.27	2.5	
	20-30cm	1.04	2.9	
	30-40cm	0.99	1.5	
	40-50cm	1.03	1.0	
	50-75cm	1.53	0.3	
	75-100cm	1.45	0.2	

Profile 22

A-22.1: General information of profile 22.

South African Classification	*Av1200*
USDA Classification	Plinthic Haplustox
Location (GPS coordinates)	*S29.19399° E030.50589°*
Altitude (m)	*993*
Land Use	*Farming*

A-22.2: Description and comments of profile 22.

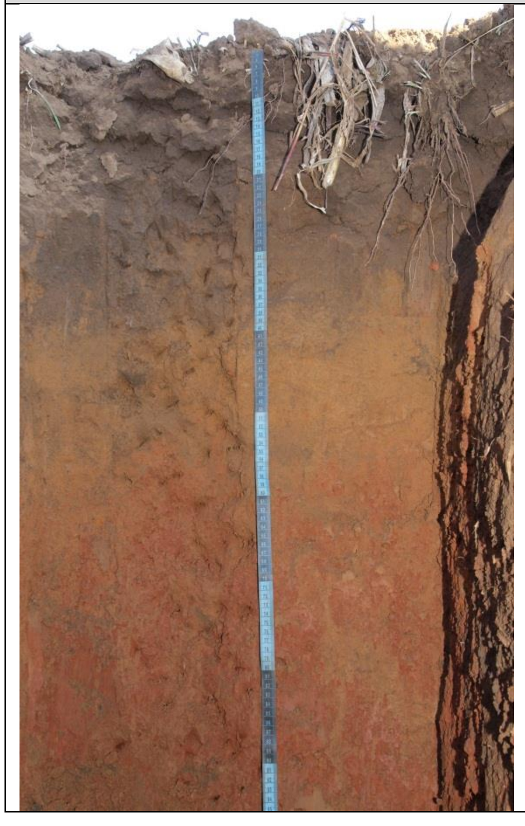
Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.11	2.9	• Harvested maize • Reduce Tillage • Orthic A 0-10cm. • Yellow-brown apedal B 10-45cm. • Soft plinthic > 45cm.
	5-10cm	1.36	2.1	
	10-15cm	1.38	1.8	
	15-20cm	1.26	1.9	
	20-30cm	1.39	2.3	
	30-40cm	1.37	1.9	
	40-50cm	1.42	0.6	
	50-75cm	1.46	0.1	
	75-100cm	1.57	0.1	

Profile 23

A-23.1: General information of profile 23.

South African Classification	*Av1200*
USDA Classification	Plinthic Haplustox
Location (GPS coordinates)	*S29.19009° E030.50650°*
Altitude (m)	*981*
Land Use	*Farming*

A-23.2: Description and comments of profile 23.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.12	2.5	• Harvested Maize • Reduce Tillage • Orthic A 0-30cm. • Yellow-brown apedal B 30-60cm. • Soft plinthic > 60cm.
	5-10cm	1.38	1.8	
	10-15cm	1.41	1.6	
	15-20cm	1.48	1.7	
	20-30cm	1.50	1.1	
	30-40cm	1.42	0.7	
	40-50cm	1.40	0.5	
	50-75cm	1.60	0.2	
	75-100cm	1.60	0.1	

Profile 24

A-24.1: General information of profile 24.

South African Classification	*Ia1200*
USDA Classification	Humic Rhodic Haplustox
Location (GPS coordinates)	*S29.19559° E030.50532°*
Altitude (m)	*1000*
Land Use	*Farming*

A-24.2: Description and comments of profile 24.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.13	3.5	• Harvested maize with stubble. • Reduce Tillage • Humic A 0-33cm. • Red apedal B > 33cm.
	5-10cm	1.22	2.5	
	10-15cm	1.19	2.1	
	15-20cm	1.24	1.7	
	20-30cm	1.19	1.6	
	30-40cm	1.25	0.8	
	40-50cm	1.10	0.6	
	50-75cm	1.16	0.4	
	75-100cm	1.26	0.4	

Profile 25

A-25.1: General information of profile 25.

South African Classification	*Ia1100*
USDA Classification	Humic Rhodic Haplustox
Location (GPS coordinates)	*S29.19674° E030.50414*
Altitude (m)	*1010*
Land Use	*Farming*

A-25.2: Description and comments of profile 25.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.85	2.9	• Harvested maize with stubble. • Reduce Tillage • Humic A (Lithocutanic) 0-38cm. • Red apedal B 38-73cm. • Dolerite >73cm.
	5-10cm	0.96	2.5	
	10-15cm	1.06	2.3	
	15-20cm	1.18	2.2	
	20-30cm	1.20	2.4	
	30-40cm	1.15	1.9	
	40-50cm	1.05	1.8	
	50-75cm	1.08	0.8	
	75-100cm	1.21	0.5	

Profile 26

A-26.1: General information of profile 26.

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.19838° E030.50381°*
Altitude (m)	*1029*
Land Use	*Farming*

A-26.2: Description and comments of profile 26.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.98	3.1	• Harvested maize • Reduce Tillage • Dolerite >103cm. • Stone layer 44-56cm.
	5-10cm	1.25	2.3	
	10-15cm	1.25	2.5	
	15-20cm	1.28	2.2	
	20-30cm	1.30	1.6	
	30-40cm	1.34	0.9	
	40-50cm	1.22	0.6	
	50-75cm	1.16	0.3	
	75-100cm	1.17	0.4	

Profile 27

A-27.1: General information of profile 27.

South African Classification	*Ia1200*
USDA Classification	Humic Rhodic Haplustox
Location (GPS coordinates)	*S29.19881° E030.50624°*
Altitude (m)	*1007*
Land Use	*Farming*

A-27.2: Description and comments of profile 27.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.89	4.2	• Harvested maize with stubble. • Reduce tillage
	5-10cm	1.04	3.5	
	10-15cm	1.15	2.7	
	15-20cm	1.12	2.6	
	20-30cm	1.07	2.3	
	30-40cm	1.02	1.4	
	40-50cm	1.07	1.2	
	50-75cm	1.22	0.5	
	75-100cm	1.16	0.3	

Profile 28

A-28.1: General information of profile 28.

South African Classification	*Av1200*
USDA Classification	Plinthic Haplustox
Location (GPS coordinates)	*S29.19953° E030.50624*
Altitude (m)	*994*
Land Use	*Farming*

A-28.2: Description and comments of profile 28.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.09	2.5	• Stubble with new wheat stablished crop. • Reduce Tillage • Water-table appears reaching 75cm.
	5-10cm	1.36	2.2	
	10-15cm	1.32	2.1	
	15-20cm	1.40	2.0	
	20-30cm	1.42	2.1	
	30-40cm	1.24	1.0	
	40-50cm	1.34	0.7	
	50-75cm	1.57	0.1	

Profile 29

A-29.1: General information of profile 29.

South African Classification	*Kp1100*
USDA Classification	Humic Haplustox
Location (GPS coordinates)	*S29.11450° E030.55645°*
Altitude (m)	-
Land Use	*Farming*

A-29-2: Description and comments of profile 29.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.05	4.1	• Harvested sugar cane (3years on a row) • Conventional Tillage • Humic A 0-19cm • Yellow-brown apedal B 19-52cm. • Red apedal B > 52cm.
	5-10cm	1.05	3.4	
	10-15cm	1.08	3.6	
	15-20cm	1.07	2.9	
	20-30cm	1.07	2.5	
	30-40cm	1.04	2.5	
	40-50cm	1.03	1.9	
	50-75cm	1.02	1.3	
	75-100cm	1.15	0.7	

Profile 30

A-30.1: General information of profile 30.

South African Classification	*Kp1100*
USDA Classification	Humic Haplustox
Location (GPS coordinates)	*S29.11361° E030.55777°*
Altitude (m)	-
Land Use	*Farming*

A-30.2: Description and comments of profile 30.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.06	4.2	• Harvested sugar cane (3 years on a row). • Conventional Tillage • Humic A 0-10cm • Yellow-brown apedal B 10-61cm. • Red apedal B >61cm.
	5-10cm	1.06	3.6	
	10-15cm	1.06	3.6	
	15-20cm	1.06	3.5	
	20-30cm	1.09	3.5	
	30-40cm	1.10	2.8	
	40-50cm	1.06	2.5	
	50-75cm	0.95	1.1	
	75-100cm	0.90	0.6	

Profile 31

A-31.1: General information of profile 31.

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.13211° E030.60263°*
Altitude (m)	-
Land Use	*Plantation Forestry*

A-31.2: Description and comments of profile 31.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.97	3.9	• Old *Pinus patula* plantation. • Humic A 0-18cm • A/B 18-30cm • Dolerite >30cm
	5-10cm	1.14	2.7	
	10-15cm	1.01	3.0	
	15-20cm	1.04	2.0	
	20-30cm	1.14	1.9	
	30-40cm	1.14	1.0	
	40-50cm	1.16	1.0	

Profile 32

A-32.1: General infomation of profile 32.

South African Classification	*Kp1200*
USDA Classification	Humic Haplustox
Location (GPS coordinates)	-
Altitude (m)	-
Land Use	*Farming*

A-32.2: Description and comments of profile 32.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.02	2.0	• Harvested maize • Conventional Tillage • Humic A 0-11cm • Yellow-brown apedal B 11- 56cm. • Red apedal > 56cm
	5-10cm	0.98	2.1	
	10-15cm	1.14	2.0	
	15-20cm	1.17	1.6	
	20-30cm	1.13	2.0	
	30-40cm	1.22	1.4	
	40-50cm	1.10	1.4	
	50-75cm	1.00	0.8	
	75-100cm	1.10	0.5	

Profile 33

A-33.1: General information of profile 33.

South African Classification	*Gf1100*
USDA Classification	Typic Haplustox
Location (GPS coordinates)	*S29.12444° E030.60069°*
Altitude (m)	-
Land Use	*Farming*

A-33.2: Description and comments of profile 33.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.99	1.6	• Ploughed maize field • Conventional Tillage • Orthic A 0-11 • Yellow-brown apedal B 11-56cm • Red apedal > 56cm
	5-10cm	1.06	1.6	
	10-15cm	1.14	1.9	
	15-20cm	1.13	1.6	
	20-30cm	1.15	1.7	
	30-40cm	1.10	1.3	
	40-50cm	1.09	1.2	
	50-75cm	1.04	0.7	
	75-100cm	1.14	0.3	

Profile 34

A-34.1: General information of profile 34

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.12188° E030.60206°*
Altitude (m)	-
Land Use	*Farming*

A-34.2: Description and comments of profile 34.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.08	2.7	• Ploughed maize field • Conventional Tillage • Humic A 0-30cm • A/B 30-45cm • Yellow-brown apedal B 45-75cm.
	5-10cm	0.99	2.5	
	10-15cm	1.00	2.5	
	15-20cm	1.04	2.4	
	20-30cm	1.11	2.5	
	30-40cm	1.15	2.5	
	40-50cm	1.21	1.6	
	50-75cm	1.56	0.4	

Profile 35

A-35.1: General information of profile 35

South African Classification	*Gc1000*
USDA Classification	Petroferric Haplustox
Location (GPS coordinates)	*S29.12093° E030.60183°*
Altitude (m)	-
Land Use	*Farming*

A-35-2: Description and comments of profile 35.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.14	3.0	• Ploughed maize field • Conventional Tillage • Orthic 0-46cm • Yellow-brown apedal B 46-100cm • Hard plinthic B >100cm
	5-10cm	1.07	3.1	
	10-15cm	1.17	3.2	
	15-20cm	1.17	3.0	
	20-30cm	1.18	2.2	
	30-40cm	1.09	2.1	
	40-50cm	1.15	1.3	
	50-75cm	1.28	0.9	
	75-100cm	1.95	0.1	

Profile 36

A-36.1: General information of profile 36.

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.11947° E030.60075*
Altitude (m)	-
Land Use	*Grassland*

A-36.2: Description and comments of profile 36.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	1.08	4.5	• Shale and dolerite are present. • Profile presents water reaching 82cm. • Close to dam which belongs to the farm.
	5-10cm	1.17	3.6	
	10-15cm	1.18	3.0	
	15-20cm	1.39	2.8	
	20-30cm	1.41	2.2	
	30-40cm	1.58	1.0	
	40-50cm	1.68	0.9	
	50-75cm	1.60	0.3	

Profile 37

A-37.1: General information of profile 37.

South African Classification	*Pn1100*
USDA Classification	Oxyaquic Haplustox
Location (GPS coordinates)	*S29.24821° E030.42319°*
Altitude (m)	*1192*
Land Use	*Grassland*

A-37.2: Description and comments of profile 37.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.67	7.5	• Orthic A 0-20cm • Yellow-brown apedal B 20-58cm. • Red apedal B > 58cm with signs of wetness.
	5-10cm	0.75	6.0	
	10-15cm	0.75	5.1	
	15-20cm	0.77	4.8	
	20-30cm	0.91	3.0	
	30-40cm	0.95	1.9	
	40-50cm	1.18	1.3	
	50-75cm	1.36	0.3	

Profile 38

A-38.1: General information of profile 38.

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.21947° E030.51015°*
Altitude (m)	*1153*
Land Use	*Plantation Forestry*

A-38.2: Description and comments of profile 38.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.41	14.4	• *Eucalyptus sp.* About 10 years old. • Humic A 0-22cm • A/B horizon 22-37cm • Lithocutanic B > 37cm • Presence of white shale from 37cm.
	5-10cm	0.77	5.2	
	10-15cm	0.79	4.5	
	15-20cm	0.88	4.1	
	20-30cm	1.02	2.8	
	30-40cm	1.17	2.4	
	40-50cm	1.35	1.0	

Profile 39

A-39.1: General information of profile 39.

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.21910° E030.51066*
Altitude (m)	*1137*
Land Use	*Plantation Forestry*

A-39.2: Description and comments of profile 39.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.62	11.3	• *Eucalyptus sp.* Around 10 years old. • Humic A 0-36cm • Yellow-brown apedal B > 36cm.
	5-10cm	0.79	4.7	
	10-15cm	0.84	4.5	
	15-20cm	0.84	4.5	
	20-30cm	0.96	2.8	
	30-40cm	1.00	2.5	
	40-50cm	1.07	1.6	
	50-75cm	1.11	1.0	

Profile 40

A-40.1: General information of profile 40.

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.21841° E030.51151*
Altitude (m)	*1127*
Land Use	*Plantation Forestry*

A-40.2: Description and comments of profile 40.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.70	5.9	• Humic A 0-34cm • Yellow-brown apedal B > 34cm. • *Eucalyptus sp.* Around 10 years old.
	5-10cm	0.73	4.9	
	10-15cm	0.77	4.8	
	15-20cm	0.86	4.4	
	20-30cm	0.92	3.4	
	30-40cm	0.97	2.9	
	40-50cm	0.94	2.6	
	50-75cm	0.94	1.6	

Profile 41

A-41.1: General information of profile 41.

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.21799° E030.51156°*
Altitude (m)	*1131*
Land Use	*Plantation Forestry*

A-41.2: Description and comments of profile 41.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.62	11.2	• Humic A 0-10cm • Yellow-brown >10cm • *Eucalyptus sp.*
	5-10cm	0.76	5.6	
	10-15cm	0.77	5.1	
	15-20cm	0.81	4.6	
	20-30cm	0.90	3.8	
	30-40cm	0.88	2.9	
	40-50cm	0.92	2.7	
	50-75cm	0.97	1.4	

Profile 42

A-42.1: General information of profile 42.

South African Classification	*Kp1200*
USDA Classification	Humic Haplustox
Location (GPS coordinates)	*S29.24857° E030.42359°*
Altitude (m)	-
Land Use	*Grassland*

A-42.2: Description and comments of profile 42.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.95	5.2	• Humic A 0-24cm • Yellow-brown apedal B 24-53cm. • Red apedal B > 53cm
	5-10cm	1.10	3.5	
	10-15cm	1.08	2.8	
	15-20cm	1.01	2.9	
	20-30cm	1.20	2.4	
	30-40cm	1.24	1.5	
	40-50cm	1.30	1.2	
	50-75cm	1.52	0.5	
	75-100cm	1.51	0.3	

Profile 43

A-43.1: General information of profile 43

South African Classification	*No1100*
USDA Classification	Lithic Humustept
Location (GPS coordinates)	*S29.22060° E030.51045°*
Altitude (m)	*1153*
Land Use	*Plantation Forestry*

A-43.2: Description and comments of profile 43.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.58	13.0	• *Eucalyptus sp.* 1 year old planted after Wattle. • Humic A 0-40cm • Lithocutanic B > 40cm • Presence of shale
	5-10cm	0.86	5.7	
	10-15cm	0.85	5.0	
	15-20cm	0.83	4.6	
	20-30cm	0.97	3.0	
	30-40cm	1.12	1.8	
	40-50cm	1.37	0.5	

Profile 44

A-44.1: General information of profile 44.

South African Classification	*Ma1200*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.22045° E030.51123*
Altitude (m)	*1144*
Land Use	*Plantation Forestry*

A-44.2: Description and comments of profile 44.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.71	7.8	• *Eucalyptus sp.* 1 year old planted after Wattle. • Humic A 0-36cm • A/B horizon 36-53cm • Yellow-brown apedal B >53cm.
	5-10cm	0.83	5.5	
	10-15cm	0.90	4.9	
	15-20cm	0.90	4.6	
	20-30cm	1.11	3.0	
	30-40cm	1.31	1.8	
	40-50cm	1.41	1.2	
	50-75cm	1.18	0.7	

Profile 45

A-45.1: General information of profile 45.

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.22008° E030.51264*
Altitude (m)	*1117*
Land Use	*Plantation Forestry*

A-45.2: Description and comments of profile 45.

<table>
<tr><th>Profile Picture</th><th>Sampling Depth</th><th>Bulk Density (g/cm³)</th><th>Carbon Content (%)</th><th>Comments</th></tr>
<tr><td rowspan="9"></td><td>0-5cm</td><td>0.71</td><td>8.0</td><td rowspan="9">• Eucalyptus sp.
• Profile located on a steep slope.
• Humic A 0-27cm
• Yellow-brown apedal B >27cm.
• Deep soil.
• Signs of shale all around.</td></tr>
<tr><td>5-10cm</td><td>0.65</td><td>5.8</td></tr>
<tr><td>10-15cm</td><td>0.77</td><td>4.5</td></tr>
<tr><td>15-20cm</td><td>0.82</td><td>4.5</td></tr>
<tr><td>20-30cm</td><td>0.94</td><td>3.7</td></tr>
<tr><td>30-40cm</td><td>1.00</td><td>2.8</td></tr>
<tr><td>40-50cm</td><td>1.07</td><td>2.7</td></tr>
<tr><td>50-75cm</td><td>1.12</td><td>1.7</td></tr>
<tr><td>75-100cm</td><td>1.05</td><td>1.3</td></tr>
</table>

Profile 46

A-46.1: General information of profile 46.

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.21940° E030.51454*
Altitude (m)	*1093*
Land Use	*Plantation Forestry*

A-46.2: Description and comments of profile 46.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.82	6.0	• Humic A 0-13cm • Yellow-brown apedal B >13cm • Steep slope • *Eucalyptus sp.* 1 year old
	5-10cm	0.95	3.4	
	10-15cm	1.01	3.0	
	15-20cm	1.06	3.0	
	20-30cm	1.07	2.7	
	30-40cm	1.18	2.2	
	40-50cm	1.14	1.8	
	50-75cm	1.24	1.4	
	75-100cm	1.26	0.78	

Profile 47

A-47.1: General information of profile 47.

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.21959° E030.51574°*
Altitude (m)	*1075*
Land Use	*Plantation Forestry*

A-47.2: Description and comments of profile 47.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.86	6.9	• Bottom of slope, *Eucalyptus sp.* 1 year old. • Humic 0-35cm • Yellow-brown apedal B >35cm • Signs of dolerite
	5-10cm	0.83	4.6	
	10-15cm	0.91	4.3	
	15-20cm	0.94	3.9	
	20-30cm	0.99	3.2	
	30-40cm	1.04	3.2	
	40-50cm	1.07	2.3	
	50-75cm	1.15	2.1	
	75-100cm	1.19	0.8	

Profile 48

A-48.1: General information of profile 48

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.21583° E030.51574°*
Altitude (m)	*1107*
Land Use	*Plantation Forestry*

A-48.2: Description and comments of profile 48.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.62	9.2	• *Pinus patula,* around 10 years old. • Humic A 0-29cm • Yellow brown apedal B >29cm • Dolerite signs >73cm
	5-10cm	0.70	6.3	
	10-15cm	0.83	4.6	
	15-20cm	0.94	3.9	
	20-30cm	1.09	2.7	
	30-40cm	1.08	3.0	
	40-50cm	1.09	2.1	
	50-75cm	1.12	0.9	

Profile 49

A-49.1: General information of profile 49.

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.21582° E030.50487°*
Altitude (m)	*1099*
Land Use	*Plantation Forestry*

A-49.2: Description and comments of profile 49.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.82	5.0	• *Pinus patula* • Humic 0-15cm • Yellow-brown apedal B >15cm. • Parent material cannot be seen.
	5-10cm	0.90	3.9	
	10-15cm	0.91	3.6	
	15-20cm	0.94	4.2	
	20-30cm	1.05	2.8	
	30-40cm	1.09	2.5	
	40-50cm	1.06	2.3	
	50-75cm	1.18	0.9	

Profile 50

A-50.1: General information of profile 50.

South African Classification	*Ma1100*
USDA Classification	Humic Xanthic Haplustox
Location (GPS coordinates)	*S29.21563° E030.50449°*
Altitude (m)	*1092*
Land Use	*Plantation Forestry*

A-50.2: Description and comments of profile 50.

Profile Picture	Sampling Depth	Bulk Density (g/cm³)	Carbon Content (%)	Comments
	0-5cm	0.82	6.9	• Lowest point on the slope. • *Pinus patula* • Humic A 0-15cm • Yellow-brown apedal B >15cm.
	5-10cm	0.98	4.1	
	10-15cm	1.00	3.7	
	15-20cm	0.98	3.4	
	20-30cm	1.11	2.7	
	30-40cm	1.10	2.2	
	40-50cm	1.13	1.8	
	50-75cm	1.23	0.9	

ADDENDUM B. PARTICLE SIZE DISTRIBUTION

Particle size distribution determined by particle size analyzer and corrected by loss on ignition (LOI).

B-1: Abbreviations used in the addendum.

Abbreviation	Concept
LOI	Loss on Ignition
PSD/PSA	Particle Size Distribution / Particle Size Analyzer
WB	Walkey & Black

B-2: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 1.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*%*	*C, %*	*%Clay*	*%Silt*	*%Sand*	Sand %	Silt %	Clay %
0-5cm	25.0	8.8	6.067	51.751	42.182	38.256	46.934	14.809
5-10cm	20.8	6.4	4.558	49.221	46.221	41.990	44.716	13.294
10-15cm	19.2	4.7	3.972	43.478	52.550	47.171	39.027	13.802
15-20cm	19.9	5.2	4.159	48.869	46.971	42.220	43.926	13.854
20-30cm	17.5	4.5	2.198	27.553	70.249	63.845	25.041	11.115
30-40cm	11.6	1.3	1.550	15.207	83.243	76.097	13.902	10.002
40-50cm	11.3	1.3	1.167	9.076	89.758	82.200	8.311	9.489

B-3: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 2.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Natural Forest	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	**Sand %**	**Silt %**	**Clay %**
0-5cm	28.3	7.4	2.743	24.184	73.072	63.026	20.860	16.114
5-10cm	22.2	4.5	5.424	33.950	60.626	52.805	29.571	17.624
10-15cm	21.2	4.9	2.804	23.321	73.875	65.384	20.640	13.976
15-20cm	18.6	3.7	5.069	34.946	59.985	53.391	31.104	15.505
20-30cm	18.0	4.1	3.696	27.465	68.839	61.973	24.726	13.302
30-40cm	13.8	2.2	3.852	24.097	72.051	65.365	21.861	12.774
40-50cm	6.9	0.1	4.841	22.293	72.866	68.220	20.872	10.908

B-4: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 3.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	**Sand %**	**Silt %**	**Clay %**
0-5cm	22.1	4.8	3.393	22.930	73.677	64.608	20.108	15.284
5-10cm	21.6	3.9	2.789	19.577	77.634	67.482	17.017	15.501
10-15cm	21.7	4.9	2.472	20.916	76.612	67.483	18.424	14.094
15-20cm	20.9	4.5	1.898	7.654	90.448	79.693	6.743	13.564
20-30cm	16.6	1.4	3.005	23.432	73.563	64.390	20.511	15.099
30-40cm	15.6	1.6	3.988	27.372	68.639	60.738	24.222	15.040
40-50cm	14.4	0.9	3.435	26.819	69.746	61.836	23.778	14.386

B-5: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 4.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	**Sand %**	**Silt %**	**Clay %**
0-5cm	51.8	28.0*	5.609	62.876	31.515	29.994	59.842	10.164
5-10cm	25.4	7.8	4.987	51.607	43.405	38.619	45.916	15.465
10-15cm	20.9	4.6	6.080	48.077	45.843	40.486	42.459	17.055
15-20cm	19.3	4.5	5.830	51.289	42.881	38.344	45.863	15.793
20-30cm	18.6	3.2	4.429	34.943	60.628	53.558	30.868	15.575
30-40cm	16.0	1.7	4.653	32.524	62.822	55.464	28.715	15.822
40-50cm	15.0	0.9	5.771	32.913	61.316	54.060	29.018	16.922
50-75cm	14.1	0.9	6.406	40.944	52.650	46.740	36.348	16.912

B-6: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 5.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	27.0	9.8	3.111	30.936	65.953	59.589	27.950	12.461
5-10cm	19.2	4.2	4.568	51.358	44.074	39.303	45.799	14.898
10-15cm	18.7	4.1	4.746	51.088	44.166	39.487	45.675	14.839
15-20cm	18.5	3.8	5.277	57.405	37.318	33.277	51.188	15.535
20-30cm	16.9	2.6	2.971	36.812	60.217	53.528	32.723	13.749
30-40cm	16.2	2.3	4.114	36.818	59.068	52.541	32.749	14.710
40-50cm	15.2	2.5	3.283	31.710	65.007	58.546	28.559	12.895
50-75cm	13.6	0.7	5.029	34.848	60.123	53.441	30.976	15.583
75-100cm	12.7	3.4	7.060	38.166	54.774	51.197	35.674	13.129

B-7: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 6.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	34.2	9.8	3.377	39.157	57.466	48.778	33.237	17.985
5-10cm	19.8	4.0	4.154	33.239	62.606	55.343	29.383	15.274
10-15cm	19.3	3.0	3.283	32.621	64.095	56.129	28.567	15.305
15-20cm	19.2	3.1	2.401	20.475	77.124	67.638	17.957	14.405
20-30cm	18.1	2.3	2.664	21.905	75.431	66.013	19.170	14.817
30-40cm	16.1	1.1	1.681	14.269	84.051	73.626	12.499	13.875
40-50cm	15.1	1.0	4.567	34.544	60.889	53.665	30.446	15.890
50-75cm	12.8	0.3	4.981	20.434	74.585	66.376	18.185	15.440
75-100cm	12.3	0.3	3.130	17.882	78.988	70.621	15.988	13.391

B-8: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 7.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	20.2	5.0	2.923	37.353	59.724	53.375	33.382	13.243
5-10cm	11.3	2.4	2.957	23.014	74.029	69.042	21.463	9.495
10-15cm	11.1	1.8	1.265	17.218	81.517	75.448	15.936	8.617
15-20cm	9.2	1.3	2.169	24.936	72.895	68.161	23.317	8.522
20-30cm	7.7	0.8	1.515	13.701	84.783	79.718	12.883	7.399
30-40cm	7.0	0.5	1.524	14.611	83.865	79.070	13.776	7.155
40-50cm	6.9	0.6	2.289	21.029	76.682	72.364	19.845	7.791

B-9: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 8.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Grassland	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	16.2	3.4	4.559	39.578	55.864	50.554	35.816	13.630
5-10cm	12.2	2.7	5.598	41.392	53.010	49.205	38.421	12.373
10-15cm	12.1	2.3	4.702	38.863	56.434	52.175	35.930	11.895
15-20cm	11.8	2.1	4.033	34.815	61.151	56.495	32.165	11.340
20-30cm	10.9	1.7	2.840	24.029	73.131	67.728	22.254	10.018
30-40cm	9.7	1.4	3.012	24.275	72.713	67.697	22.600	9.704
40-50cm	8.9	0.8	3.386	23.824	72.791	67.675	22.149	10.175

B-10: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 10.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Grassland	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	25.0	5.5	6.787	51.367	41.846	36.127	44.347	19.526
5-10cm	24.0	4.6	5.067	40.002	54.931	47.208	34.378	18.414
10-15cm	21.7	4.7	4.620	40.130	55.250	48.532	35.251	16.218
15-20cm	22.6	2.5	11.623	47.655	40.721	34.378	40.232	25.390

B-11: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 11.

	LOI	**WB**	**PSD (PSA)**			**PSD, corrected by LOI**		
Plantation Forestry	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	35.7	10.5	3.742	41.288	54.970	46.497	34.923	18.580
5-10cm	19.6	2.9	3.605	39.458	56.936	49.629	34.394	15.976
10-15cm	19.7	3.2	1.932	25.848	72.221	63.111	22.587	14.302
15-20cm	20.2	2.7	3.158	25.069	71.772	62.068	21.680	16.252
20-30cm	18.4	1.7	2.754	20.237	77.009	66.662	17.518	15.821
30-40cm	16.5	1.1	1.350	14.921	83.729	73.037	13.016	13.947
40-50cm	16.3	0.7	4.115	26.365	69.520	60.343	22.885	16.772
50-75cm	15.5	0.8	3.701	26.010	70.289	61.578	22.787	15.635
75-100cm	14.0	0.4	3.642	20.107	76.251	67.270	17.739	14.991

B-12: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 12.

	LOI	**WB**	**PSD (PSA)**			**PSD, corrected by LOI**		
Grassland	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	20.1	4.3	2.677	28.694	68.628	60.744	25.398	13.858
5-10cm	19.4	3.6	2.324	26.833	70.843	62.454	23.656	13.890
10-15cm	18.3	2.9	2.218	22.483	75.300	66.345	19.809	13.845
15-20cm	17.2	2.3	2.357	22.194	75.450	66.530	19.570	13.900
20-30cm	15.9	1.4	2.326	22.986	74.688	65.770	20.242	13.988
30-40cm	15.0	0.9	2.717	23.711	73.571	64.878	20.910	14.213
40-50cm	13.8	0.7	4.392	37.639	57.969	51.409	33.379	15.212
50-75cm	12.9	0.6	5.024	37.393	57.583	51.439	33.403	15.158
75-100cm	14.7	0.3	4.820	39.889	55.292	48.458	34.959	16.584

B-13: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 13.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Natural Forest	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	19.8	5.6	4.174	39.234	56.592	51.243	35.525	13.232
5-10cm	17.6	4.5	5.728	39.689	54.583	49.565	36.040	14.396
10-15cm	16.4	3.1	3.787	31.324	64.889	58.335	28.161	13.505
15-20cm	15.8	2.5	5.041	38.366	56.592	50.691	34.366	14.943
20-30cm	14.5	2.7	6.095	38.047	55.858	50.814	34.611	14.576
30-40cm	12.0	1.3	5.976	40.445	53.579	48.760	36.807	14.432
40-50cm	13.7	1.2	6.540	40.319	53.141	47.595	36.111	16.294

B-14: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 14.

Profile 14	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	43.3	12.5	4.817	54.293	40.890	33.386	44.329	22.285
5-10cm	34.2	9.2	5.349	55.488	39.164	32.952	46.688	20.360
10-15cm	31.6	8.6	3.511	52.730	43.758	37.306	44.956	17.738
15-20cm	27.4	6.0	3.225	37.172	59.603	50.778	31.668	17.553
20-30cm	19.4	1.5	4.145	35.429	60.426	51.698	30.312	17.990
30-40cm	18.4	2.1	5.097	34.801	60.102	52.325	30.298	17.377
40-50cm	18.4	1.7	5.848	41.762	52.390	45.324	36.130	18.546
50-75cm	12.7	0.7	4.517	17.614	77.869	69.792	15.787	14.421
75-100cm	8.9	0.1	10.071	53.623	36.306	33.385	49.307	17.308

B-15: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 16.

Profile 16	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	18.8	7.5	13.641	65.585	20.774	19.543	61.699	18.758
5-10cm	27.9	7.8	10.110	60.301	29.590	25.765	52.507	21.729
10-15cm	26.3	7.0	8.582	61.323	30.095	26.269	53.527	20.204
15-20cm	24.4	7.0	6.897	61.766	31.337	27.822	54.838	17.340
20-30cm	20.5	4.4	5.250	51.796	42.953	37.940	45.751	16.309
30-40cm	17.5	2.9	7.655	49.952	42.393	37.653	44.367	17.980
40-50cm	16.5	2.5	8.339	52.275	39.387	35.076	46.554	18.370
50-75cm	6.5	0.2	10.242	65.974	23.784	22.397	62.128	15.475

B-16: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 17.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	38.2	11.5	18.110	62.789	19.101	16.067	52.813	31.120
5-10cm	32.3	8.9	11.393	44.874	43.733	37.219	38.190	24.590
10-15cm	30.7	8.4	4.515	32.600	62.885	53.916	27.950	18.134
15-20cm	28.9	5.1	5.884	49.276	44.840	37.234	40.918	21.848
20-30cm	24.2	3.3	7.588	33.796	58.616	49.383	28.472	22.145
30-40cm	24.5	0.4	13.372	43.232	43.397	35.043	34.909	30.048
40-50cm	19.8	1.1	14.789	38.960	46.251	39.184	33.008	27.808
50-75cm	16.5	0.5	11.720	27.963	60.317	52.119	24.162	23.719

B-17: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 18.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	14.4	2.1	3.589	29.976	66.435	59.925	27.038	13.037
5-10cm	14.6	2.0	4.284	36.433	59.283	53.288	32.748	13.964
10-15cm	15.2	1.9	6.719	54.558	38.723	34.541	48.666	16.793
15-20cm	15.0	1.8	3.938	35.793	60.269	53.819	31.963	14.219
20-30cm	14.8	1.9	6.958	55.875	37.167	33.277	50.026	16.698
30-40cm	14.6	1.7	6.075	51.624	42.300	37.849	46.192	15.958
40-50cm	13.4	1.7	3.647	33.628	62.725	56.742	30.421	12.837
50-75cm	11.6	0.6	5.328	43.403	51.270	46.368	39.253	14.379
75-100cm	9.6	0.2	3.747	31.531	64.722	59.254	28.867	11.878

B-18: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 19.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	15.8	2.9	5.685	43.537	50.779	45.744	39.220	15.036
5-10cm	16.3	3.3	6.112	45.449	48.439	43.720	41.021	15.260
10-15cm	16.3	2.7	4.395	37.591	58.014	51.914	33.639	14.447
15-20cm	16.5	2.9	5.710	47.701	46.589	41.760	42.756	15.483
20-30cm	14.8	2.0	3.019	34.475	62.506	56.025	30.900	13.075
30-40cm	12.0	N/A	3.628	20.471	75.901	N/A	N/A	N/A
40-50cm	12.0	N/A	5.886	44.544	49.570	N/A	N/A	N/A
50-75cm	8.3	0.2	2.769	11.639	85.592	79.270	10.779	9.950

B-19: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 20.

Profile 20	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	14.6	2.1	4.290	40.902	54.808	49.352	36.831	13.817
5-10cm	15.6	3.1	4.589	40.012	55.398	50.181	36.244	13.575
10-15cm	15.7	2.9	5.309	46.523	48.168	43.463	41.979	14.558
15-20cm	15.8	2.7	4.293	40.648	55.059	49.506	36.549	13.945
20-30cm	13.0	0.5	2.365	24.832	72.803	64.922	22.144	12.934
30-40cm	10.1	0.5	2.877	20.376	76.747	70.242	18.649	11.109
40-50cm	7.2	0.2	4.742	23.707	71.551	66.941	22.179	10.880

B-20: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 21.

Profile 21	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	14.5	2.9	4.993	29.081	65.926	60.051	26.489	13.460
5-10cm	14.1	2.5	5.679	36.219	58.102	52.863	32.954	14.183
10-15cm	14.3	2.5	4.602	30.065	65.333	59.362	27.317	13.321
15-20cm	14.3	2.5	6.086	41.393	52.521	47.704	37.597	14.698
20-30cm	16.3	2.9	2.613	19.236	78.151	70.103	17.255	12.642
30-40cm	13.4	1.5	4.267	31.838	63.895	57.625	28.713	13.662
40-50cm	11.2	1.0	3.181	25.351	71.468	65.227	23.137	11.635
50-75cm	2.3	0.3	1.466	15.171	83.364	81.835	14.893	3.272
75-100cm	2.9	0.2	3.064	23.893	73.044	71.196	23.288	5.515

B-21: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 22.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	17.1	2.9	5.548	43.029	51.423	45.816	38.337	15.847
5-10cm	13.5	2.1	3.375	17.824	78.802	71.604	16.196	12.200
10-15cm	12.8	1.8	5.613	45.046	49.341	44.948	41.035	14.017
15-20cm	13.5	1.9	4.540	37.312	58.149	52.667	33.794	13.538
20-30cm	13.2	2.3	5.250	44.963	49.786	45.497	41.089	13.414
30-40cm	12.9	1.9	4.905	36.438	58.657	53.432	33.192	13.377
40-50cm	10.9	0.6	7.020	41.432	51.548	46.861	37.664	15.475
50-75cm	8.7	0.1	2.651	29.428	67.920	62.534	27.095	10.371
75-100cm	9.0	0.1	1.843	18.919	79.238	72.761	17.373	9.866

B-22: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 23.

	LOI	WB	Texture (PSA)			Texture		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	8.1	2.5	4.435	47.870	47.695	45.903	46.071	8.026
5-10cm	7.6	1.8	5.188	54.114	40.698	38.870	51.683	9.447
10-15cm	6.6	1.6	4.424	45.540	50.036	48.103	43.781	8.116
15-20cm	8.0	1.7	3.654	40.843	55.503	52.758	38.824	8.418
20-30cm	7.5	1.1	2.959	29.202	67.840	64.199	27.635	8.166
30-40cm	7.5	0.7	3.144	32.666	64.190	60.403	30.739	8.858
40-50cm	7.6	0.5	2.797	35.939	61.263	57.418	33.683	8.899
50-75cm	6.1	0.2	1.783	22.769	75.448	71.326	21.525	7.149
75-100cm	4.5	0.1	2.963	31.318	65.718	63.011	30.028	6.961

B-23: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 24.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	18.8	3.5	4.408	42.246	53.346	47.241	37.412	15.347
5-10cm	17.0	2.5	4.259	41.382	54.359	48.154	36.658	15.189
10-15cm	16.7	2.1	4.339	37.486	58.175	51.410	33.127	15.463
15-20cm	16.2	1.7	3.059	25.180	71.762	63.298	22.210	14.492
20-30cm	15.7	1.6	3.333	31.714	64.953	57.511	28.080	14.409
30-40cm	14.9	0.8	3.326	32.670	64.004	56.397	28.787	14.816
40-50cm	14.7	0.6	2.675	31.174	66.151	58.175	27.416	14.409
50-75cm	14.8	0.4	2.802	26.970	70.228	61.509	23.622	14.869
75-100cm	14.2	0.4	2.910	28.405	68.685	60.460	25.004	14.535

B-24: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 25.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	19.7	2.9	6.466	28.866	64.668	56.298	25.130	18.572
5-10cm	19.4	2.5	6.273	25.870	67.857	58.921	22.463	18.615
10-15cm	19.0	2.3	12.995	40.201	46.804	40.647	34.912	24.441
15-20cm	17.6	2.2	9.120	29.900	60.980	53.565	26.264	20.171
20-30cm	18.4	2.4	7.242	27.778	64.980	56.803	24.282	18.915
30-40cm	19.0	1.9	7.099	25.557	67.344	58.165	22.073	19.762
40-50cm	18.7	1.8	4.537	16.863	78.600	67.978	14.584	17.438
50-75cm	17.2	0.8	8.121	21.632	70.247	60.648	18.676	20.676
75-100cm	15.7	0.5	5.395	18.551	76.054	66.162	16.138	17.701

B-25: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 26.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	19.0	3.1	4.731	33.130	62.140	54.611	29.116	16.273
5-10cm	17.6	2.3	8.401	44.189	47.410	41.687	38.854	19.460
10-15cm	17.1	2.5	10.524	50.124	39.351	34.850	44.391	20.759
15-20cm	17.0	2.2	9.235	37.354	53.411	47.137	32.966	19.897
20-30cm	17.1	1.6	7.384	29.870	62.746	54.849	26.111	19.040
30-40cm	17.0	0.9	3.968	20.568	75.464	65.319	17.803	16.878
40-50cm	19.7	0.6	10.269	40.043	49.688	41.838	33.717	24.444
50-75cm	15.4	0.3	2.748	14.968	82.284	71.620	13.028	15.352
75-100cm	15.5	0.4	4.217	32.913	62.870	54.755	28.664	16.580

B-26: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 27.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	19.0	4.2	6.893	45.777	47.330	42.278	40.891	16.831
5-10cm	17.9	3.5	10.329	51.681	37.990	33.911	46.132	19.956
10-15cm	17.2	2.7	7.997	40.898	51.105	45.390	36.325	18.285
15-20cm	17.5	2.6	6.860	41.876	51.265	45.327	37.026	17.647
20-30cm	17.1	2.3	5.552	35.935	58.513	51.684	31.741	16.574
30-40cm	16.1	1.4	4.140	29.199	66.661	58.592	25.665	15.744
40-50cm	15.5	1.2	5.344	36.087	58.569	51.564	31.771	16.665
50-75cm	14.2	0.5	6.301	41.831	51.869	45.743	36.890	17.367
75-100cm	12.6	0.3	4.960	32.687	62.353	55.636	29.165	15.199

B-27: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 28.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	11.2	2.5	4.726	37.271	58.003	54.203	34.830	10.967
5-10cm	10.9	2.2	4.103	33.407	62.490	58.261	31.146	10.593
10-15cm	10.4	2.1	4.484	41.477	54.039	50.526	38.781	10.692
15-20cm	10.1	2.0	2.895	26.711	70.394	65.840	24.983	9.176
20-30cm	10.0	2.1	3.067	28.146	68.788	64.587	26.427	8.986
30-40cm	10.3	1.0	3.735	36.127	60.139	55.377	33.266	11.357
40-50cm	9.1	0.7	4.964	31.750	63.286	58.618	29.408	11.975
50-75cm	8.3	0.2	7.314	30.419	62.267	57.669	28.173	14.158

B-28: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 29.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	20.0	4.1	2.546	28.074	69.380	61.335	24.819	13.847
5-10cm	19.2	3.4	3.406	27.102	69.491	61.216	23.875	14.909
10-15cm	19.4	3.6	2.577	26.262	71.161	62.777	23.168	14.054
15-20cm	19.2	2.9	1.798	17.028	81.174	70.979	14.889	14.131
20-30cm	18.4	2.5	1.411	11.055	87.535	76.634	9.678	13.688
30-40cm	18.0	2.5	2.272	18.767	78.960	69.318	16.476	14.206
40-50cm	17.5	1.9	3.942	34.364	61.693	53.995	30.076	15.930
50-75cm	15.9	1.3	2.309	24.401	73.290	64.421	21.448	14.131
75-100cm	14.5	0.7	2.799	25.673	71.528	63.094	22.646	14.259

B-29: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 30.

Profile 30	**LOI**	**WB**	**PSD (PSA)**			**PSD, corrected by LOI**		
Farming	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	16.7	4.2	3.822	46.569	49.610	45.249	42.476	12.275
5-10cm	16.8	3.6	4.006	41.003	54.991	49.666	37.033	13.302
10-15cm	17.2	3.6	2.775	32.350	64.875	58.393	29.117	12.490
15-20cm	17.2	3.5	3.388	39.170	57.443	51.600	35.185	13.215
20-30cm	17.2	3.5	2.525	27.224	70.251	63.038	24.429	12.533
30-40cm	16.4	2.8	2.297	30.021	67.683	60.545	26.855	12.601
40-50cm	15.5	2.5	1.970	27.483	70.546	63.343	24.677	11.980
50-75cm	13.4	1.1	1.623	33.459	64.918	58.231	30.012	11.756
75-100cm	12.4	0.6	1.827	37.383	60.790	54.596	33.574	11.830

B-30: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 31.

	LOI	**WB**	**PSD (PSA)**			**PSD, corrected by LOI**		
Plantation Forestry	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	18.6	3.9	3.721	46.787	49.492	44.169	41.754	14.077
5-10cm	15.9	2.7	2.175	32.057	65.768	59.052	28.783	12.164
10-15cm	17.2	3.0	1.998	25.056	72.946	65.037	22.339	12.624
15-20cm	17.4	2.0	1.754	24.004	74.241	65.128	21.057	13.815
20-30cm	17.0	1.9	1.400	16.638	81.961	71.933	14.603	13.464
30-40cm	18.1	1.0	2.845	25.972	71.183	61.133	22.305	16.562
40-50cm	18.6	1.0	3.340	28.519	68.141	58.289	24.395	17.316

B-31: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 32.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Commercial Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	15.2	2.0	2.663	25.584	71.753	64.105	22.857	13.038
5-10cm	15.7	2.1	3.010	26.531	70.459	62.809	23.650	13.541
10-15cm	16.1	2.0	1.473	6.840	91.687	81.271	6.063	12.666
15-20cm	15.8	1.6	3.641	36.965	59.394	52.524	32.689	14.787
20-30cm	15.5	2.0	0.926	6.788	92.286	82.233	6.049	11.718
30-40cm	15.7	1.4	1.448	14.007	84.545	74.554	12.352	13.095
40-50cm	15.0	1.4	3.435	34.894	61.671	54.751	30.979	14.271
50-75cm	13.9	0.8	2.440	29.542	68.018	60.460	26.260	13.280
75-100cm	13.5	0.5	2.113	23.917	73.970	65.683	21.237	13.080

B-32: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 33.

Profile 33	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Commercial Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	14.5	1.6	2.484	32.361	65.155	58.319	28.967	12.714
5-10cm	14.5	1.6	2.224	27.270	70.506	63.024	24.377	12.600
10-15cm	14.7	1.9	2.113	26.606	71.281	63.933	23.863	12.203
15-20cm	14.5	1.6	2.369	24.099	73.532	65.737	21.544	12.719
20-30cm	14.3	1.7	2.268	28.880	68.851	61.777	25.913	12.309
30-40cm	14.0	1.3	2.581	21.553	75.866	67.806	19.263	12.931
40-50cm	13.4	1.2	2.151	23.787	74.062	66.501	21.359	12.140
50-75cm	13.3	0.7	1.662	23.175	75.162	67.020	20.665	12.316
75-100cm	11.8	0.3	1.488	23.027	75.485	67.832	20.693	11.475

B-33: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 34.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Commercial Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	15.5	2.7	3.926	44.326	51.749	46.599	39.915	13.486
5-10cm	15.4	2.5	4.441	46.650	48.909	43.963	41.932	14.105
10-15cm	15.4	2.5	5.129	47.084	47.787	42.945	42.314	14.741
15-20cm	15.5	2.4	4.029	40.776	55.195	49.528	36.589	13.883
20-30cm	14.7	2.5	6.984	55.719	37.296	33.739	50.405	15.856
30-40cm	14.9	2.5	4.743	39.935	55.322	49.941	36.051	14.008
40-50cm	14.0	1.6	3.985	34.881	61.134	54.965	31.361	13.674
50-75cm	17.5	0.4	2.336	22.085	75.579	64.718	18.911	16.371

B-34: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 35.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Commercial Farming	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	15.0	3.0	3.590	44.255	52.154	47.638	40.423	11.940
5-10cm	14.8	3.1	3.147	36.997	59.856	54.637	33.772	11.591
10-15cm	14.9	3.2	3.313	38.350	58.336	53.233	34.995	11.771
15-20cm	15.0	3.0	4.118	43.829	52.053	47.371	39.887	12.741
20-30cm	14.7	2.2	1.836	22.743	75.421	68.003	20.506	11.491
30-40cm	14.6	2.1	1.930	22.884	75.186	67.722	20.612	11.666
40-50cm	13.2	1.3	1.626	14.641	83.733	75.351	13.175	11.473
50-75cm	90.5	0.9	3.485	45.750	50.765	26.848	24.195	48.957
75-100cm	10.5	0.1	1.625	22.193	76.182	69.020	20.107	10.873

B-35: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 36.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Grassland	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	14.6	4.5	2.734	35.076	62.190	58.039	32.735	9.226
5-10cm	13.0	3.6	3.053	38.616	58.331	54.482	36.068	9.450
10-15cm	11.6	3.0	3.296	36.822	59.882	56.199	34.557	9.243
15-20cm	11.2	2.8	2.321	25.143	72.536	68.066	23.593	8.341
20-30cm	10.4	2.2	3.180	33.707	63.113	59.103	31.565	9.333
30-40cm	10.0	1.0	2.259	21.892	75.849	70.066	20.224	9.710
40-50cm	10.2	0.9	2.727	28.010	69.263	63.743	25.777	10.480
50-75cm	8.8	0.3	4.596	38.142	57.262	52.882	35.224	11.894

B-36: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 37.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Grassland	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	21.3	7.5	3.961	47.415	48.624	44.690	43.579	11.731
5-10cm	18.7	6.0	3.288	34.744	61.968	57.037	31.979	10.984
10-15cm	17.8	5.1	3.370	39.667	56.963	52.091	36.275	11.633
15-20cm	17.5	4.8	4.355	44.992	50.653	46.236	41.068	12.695
20-30cm	13.1	3.0	4.534	34.683	60.783	56.290	32.119	11.591
30-40cm	10.6	1.9	3.119	33.343	63.538	59.179	31.055	9.766
40-50cm	9.7	1.3	3.786	42.148	54.066	50.304	39.215	10.480
50-75cm	7.7	0.3	4.951	61.883	33.165	30.951	57.751	11.298

B-37: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 38.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	43.6	14.4	3.700	43.843	52.457	43.832	36.635	19.533
5-10cm	23.4	5.2	4.176	33.365	62.459	54.453	29.089	16.458
10-15cm	21.3	4.5	3.679	24.688	71.633	62.981	21.706	15.313
15-20cm	20.5	4.1	5.546	31.221	63.233	55.679	27.491	16.830
20-30cm	18.9	2.8	5.568	21.943	72.489	63.447	19.206	17.348
30-40cm	16.9	2.4	7.514	27.240	65.246	57.774	24.120	18.106
40-50cm	13.0	1.0	3.575	19.499	76.926	69.111	17.518	13.371

B-38: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 39.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	33.0	11.3	4.425	41.745	53.830	47.147	36.563	16.291
5-10cm	23.9	4.7	3.636	33.035	63.330	54.601	28.481	16.918
10-15cm	22.4	4.5	4.576	36.029	59.396	51.678	31.347	16.975
15-20cm	22.4	4.5	3.574	26.805	69.621	60.539	23.309	16.152
20-30cm	20.9	2.8	3.898	21.860	74.242	63.899	18.815	17.286
30-40cm	20.0	2.5	5.911	28.228	65.861	56.837	24.360	18.803
40-50cm	17.9	1.6	10.771	34.544	54.685	47.443	29.969	22.588
50-75cm	17.0	1.0	4.831	21.263	73.906	64.092	18.440	17.468

B-39: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 40.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	27.198	5.9	5.697	48.671	45.632	38.860	41.447	19.693
5-10cm	24.032	4.9	5.547	46.403	48.051	41.483	40.060	18.457
10-15cm	23.643	4.8	4.296	36.304	59.400	51.401	31.416	17.183
15-20cm	21.384	4.4	4.238	36.324	59.438	52.099	31.839	16.062
20-30cm	20.236	3.4	4.092	28.975	66.932	58.452	25.304	16.243
30-40cm	19.404	2.9	6.447	39.676	53.877	47.036	34.638	18.326
40-50cm	18.182	2.6	8.318	41.239	50.444	44.278	36.199	19.523
50-75cm	17.229	1.6	6.516	31.188	62.296	54.348	27.209	18.443

B-40: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 41.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	34.6	11.2	5.455	55.365	39.179	33.811	47.778	18.411
5-10cm	24.8	5.6	5.046	52.110	42.844	37.086	45.107	17.807
10-15cm	22.9	5.1	3.419	40.561	56.020	49.001	35.479	15.520
15-20cm	22.5	4.6	4.517	46.659	48.825	42.506	40.621	16.873
20-30cm	21.7	3.8	5.435	44.965	49.600	43.010	38.992	17.998
30-40cm	20.4	2.9	5.823	39.015	55.162	47.726	33.756	18.518
40-50cm	35.8	2.7	5.416	34.589	59.995	45.652	26.319	28.028
50-75cm	18.0	1.4	4.782	28.734	66.484	57.505	24.853	17.643

B-41: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 42.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Grassland	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	16.2	5.2	5.360	21.673	72.967	67.832	20.148	12.020
5-10cm	14.8	3.5	4.083	39.078	56.839	52.152	35.856	11.992
10-15cm	13.6	2.8	4.651	48.212	47.137	43.252	44.238	12.510
15-20cm	13.5	2.9	3.284	36.375	60.340	55.552	33.488	10.960
20-30cm	12.7	2.4	3.155	33.400	63.445	58.358	30.722	10.919
30-40cm	10.7	1.5	1.695	15.111	83.194	76.912	13.970	9.118
40-50cm	10.4	1.2	4.451	34.622	60.927	56.221	31.948	11.831
50-75cm	10.3	0.5	22.310	53.125	24.564	22.426	48.501	29.073
75-100cm	8.2	0.3	21.267	44.275	34.458	31.986	41.098	26.916

B-42: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 43.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	39.1	13.0	5.297	44.844	49.859	42.448	38.178	19.374
5-10cm	21.4	5.7	5.922	40.399	53.679	47.976	36.107	15.917
10-15cm	19.0	5.0	4.665	31.772	63.564	57.422	28.702	13.877
15-20cm	18.4	4.6	5.447	35.432	59.121	53.383	31.993	14.623
20-30cm	16.5	3.0	6.396	31.695	61.908	55.549	28.439	16.012
30-40cm	13.5	1.8	6.323	27.709	65.968	59.702	25.077	15.221
40-50cm	8.5	0.5	8.792	44.200	47.009	43.673	41.063	15.265

B-43: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 44.

Profile 44	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	25.3	7.8	3.101	33.357	63.542	56.619	29.722	13.659
5-10cm	20.7	5.5	2.744	26.782	70.473	63.146	23.998	12.856
10-15cm	20.0	4.9	1.500	19.163	79.337	70.989	17.147	11.864
15-20cm	19.7	4.6	1.575	18.510	79.914	71.281	16.511	12.208
20-30cm	18.1	3.0	2.279	21.451	76.270	67.483	18.980	13.537
30-40cm	15.7	1.8	2.510	23.356	74.134	65.791	20.728	13.481
40-50cm	13.6	1.2	2.531	22.481	74.987	67.196	20.146	12.658
50-75cm	14.2	0.7	1.811	16.814	81.374	71.973	14.872	13.156

B-44: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 45.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	26.0	8.0	3.129	33.346	63.525	56.371	29.591	14.038
5-10cm	24.6	5.8	3.603	38.604	57.793	50.325	33.616	16.059
10-15cm	21.4	4.5	2.345	31.355	66.300	58.156	27.504	14.341
15-20cm	21.3	4.5	1.451	22.783	75.766	66.608	20.029	13.364
20-30cm	20.2	3.7	1.501	19.764	78.735	69.045	17.332	13.624
30-40cm	19.8	2.8	2.228	16.806	80.966	70.354	14.604	15.042
40-50cm	18.2	2.7	2.184	22.962	74.854	65.847	20.199	13.954
50-75cm	17.0	1.7	1.136	10.206	88.657	77.643	8.938	13.418
75-100cm	16.6	1.3	2.634	23.954	73.412	64.146	20.931	14.924

B-45: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 46.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	19.5	6.0	2.080	27.546	70.374	64.267	25.155	10.577
5-10cm	15.7	3.4	0.982	13.786	85.232	77.474	12.532	9.994
10-15cm	15.5	3.0	1.106	13.847	85.047	76.948	12.529	10.523
15-20cm	15.0	3.0	1.369	17.768	80.863	73.545	16.160	10.294
20-30cm	14.3	2.7	1.770	18.103	80.128	72.986	16.489	10.525
30-40cm	13.5	2.2	1.878	17.950	80.172	72.938	16.331	10.731
40-50cm	13.1	1.8	1.346	10.834	87.819	79.721	9.835	10.444
50-75cm	13.3	1.4	1.956	19.624	78.420	70.625	17.673	11.702
75-100cm	12.8	0.8	2.602	23.920	73.478	65.890	21.450	12.661

B-46: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 47.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	*C content %*	*C content %*	*%Clay*	*%Silt*	*%Sand*	*Sand %*	*Silt %*	*Clay %*
0-5cm	23.4	6.9	3.556	34.572	61.872	55.328	30.916	13.755
5-10cm	22.3	4.6	2.106	25.191	72.703	63.430	21.978	14.592
10-15cm	21.2	4.3	1.608	18.508	79.884	70.115	16.245	13.640
15-20cm	9.9	3.9	2.469	23.716	73.815	71.330	22.917	5.752
20-30cm	18.5	3.2	3.601	30.079	66.320	58.632	26.592	14.776
30-40cm	18.8	3.2	2.542	24.002	73.456	64.734	21.152	14.114
40-50cm	17.8	2.3	2.730	22.324	74.946	65.790	19.597	14.612
50-75cm	17.1	2.1	1.999	21.161	76.841	67.660	18.632	13.708
75-100cm	14.7	0.8	2.121	17.853	80.026	70.604	15.751	13.645

B-47: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 48.

	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	27.7	9.2	7.216	62.143	30.641	27.275	55.317	17.408
5-10cm	21.8	6.3	5.070	36.382	58.548	52.647	32.715	14.638
10-15cm	22.4	4.6	4.201	35.040	60.759	52.980	30.554	16.466
15-20cm	19.7	3.9	6.214	33.646	60.140	53.159	29.741	17.101
20-30cm	18.2	2.7	5.976	21.338	72.686	63.967	18.778	17.256
30-40cm	18.5	3.0	6.674	28.772	64.554	56.834	25.331	17.834
40-50cm	17.9	2.1	8.929	35.311	55.760	48.737	30.863	20.400
50-75cm	16.7	0.9	11.905	38.478	49.617	43.090	33.417	23.494

B-48: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 49.

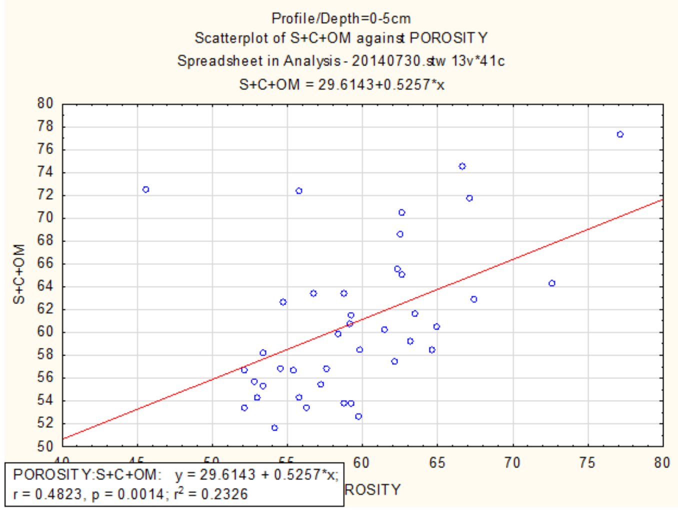
	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	22.7	5.0	2.157	26.101	71.742	62.719	22.818	14.463
5-10cm	21.0	3.9	2.074	23.779	74.147	64.819	20.787	14.394
10-15cm	21.5	3.6	0.828	11.902	87.271	75.520	10.299	14.180
15-20cm	21.1	4.2	1.042	13.268	85.690	75.052	11.621	13.327
20-30cm	20.3	2.8	1.659	12.948	85.393	73.846	11.197	14.957
30-40cm	20.1	2.5	1.238	11.461	87.302	75.356	9.892	14.752
40-50cm	19.4	2.3	1.656	14.152	84.192	72.832	12.243	14.925
50-75cm	17.3	0.9	1.560	14.935	83.505	72.121	12.899	14.981

B-49: Particle size distribution adopted from particle size analyzer results and corrected by LOI for profile 50.

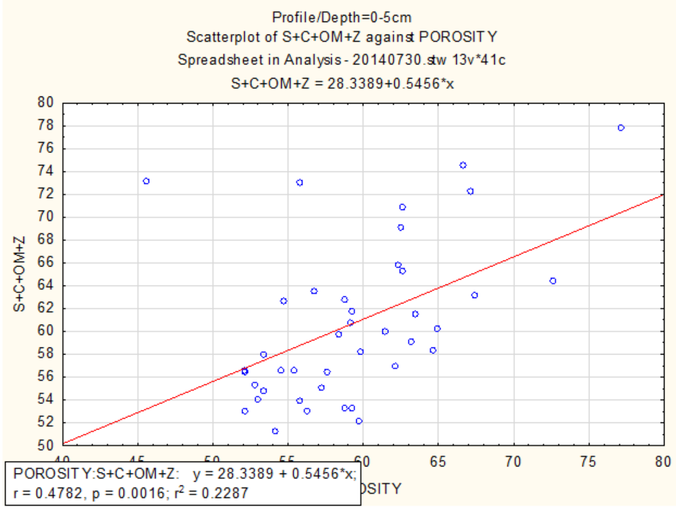
	LOI	WB	PSD (PSA)			PSD, corrected by LOI		
Plantation Forestry	***C content %***	***C content %***	***%Clay***	***%Silt***	***%Sand***	***Sand %***	***Silt %***	***Clay %***
0-5cm	19.6	6.9	3.301	41.472	55.227	51.112	38.382	10.506
5-10cm	15.5	4.1	3.286	30.527	66.187	60.914	28.095	10.991
10-15cm	15.5	3.7	2.986	31.810	65.204	59.653	29.102	11.245
15-20cm	14.6	3.4	2.999	34.434	62.568	57.397	31.588	11.014
20-30cm	14.3	2.7	2.206	20.059	77.735	70.767	18.261	10.971
30-40cm	13.4	2.2	2.794	25.707	71.498	65.136	23.420	11.444
40-50cm	13.1	1.8	1.199	15.291	83.509	75.833	13.886	10.281
50-75cm	12.2	0.9	1.958	18.950	79.092	71.444	17.117	11.438

ADDENDUM C. VALIDATION OF S&R MODEL OUTPUT FOR EVERY DEPTH INCREMENT

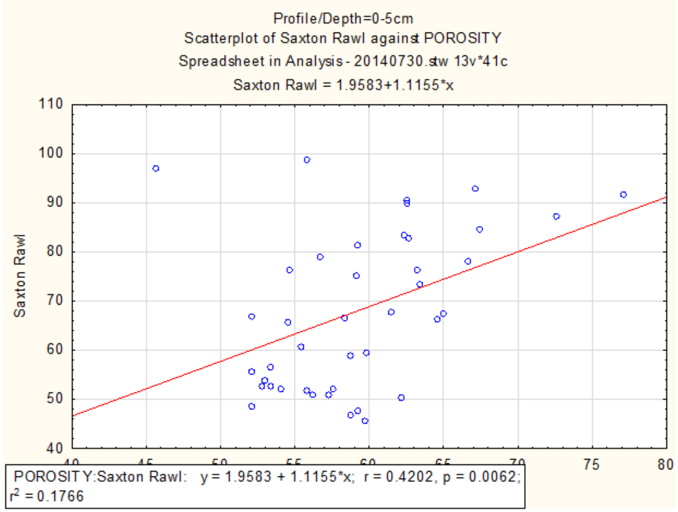
C-1: Correlation of independent variables for the regressions and Saxton&Rawls model in 0-5cm increment.



S+C+OM regression correlation with field porosity. R^2= 0.4823

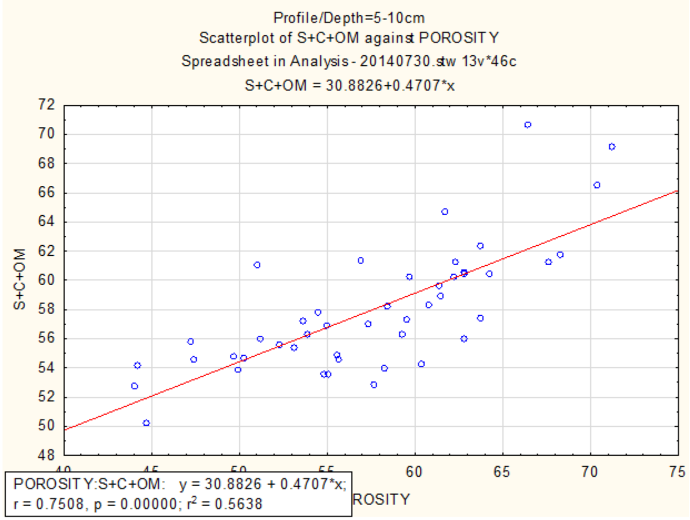


S+C+OM+Z regression correlation with field porosity. R^2= 0.4782

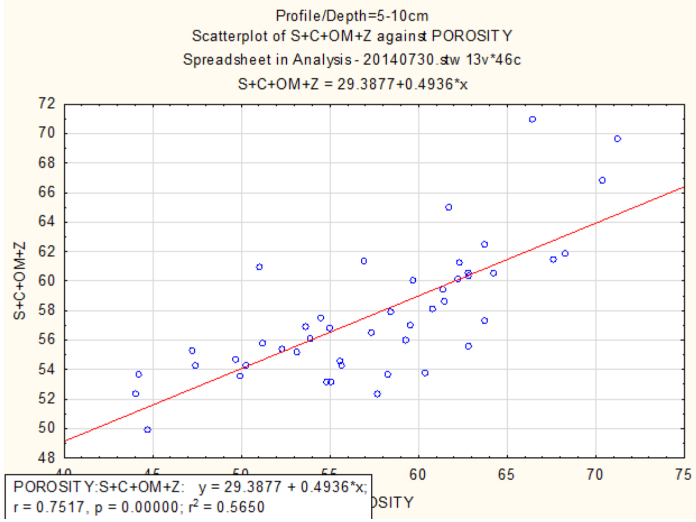


Saxton&Rawls model correlation with porosity. R^2= 0.1766.

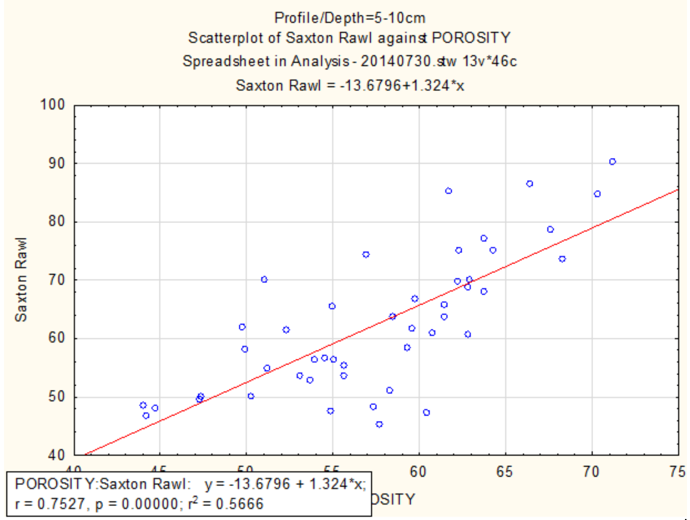
C-2: Correlation of independent variables for the regressions and Saxton &Rawls model in 5-10cm increment.



S+C+OM regression correlation with porosity. R^2= 0.5638.

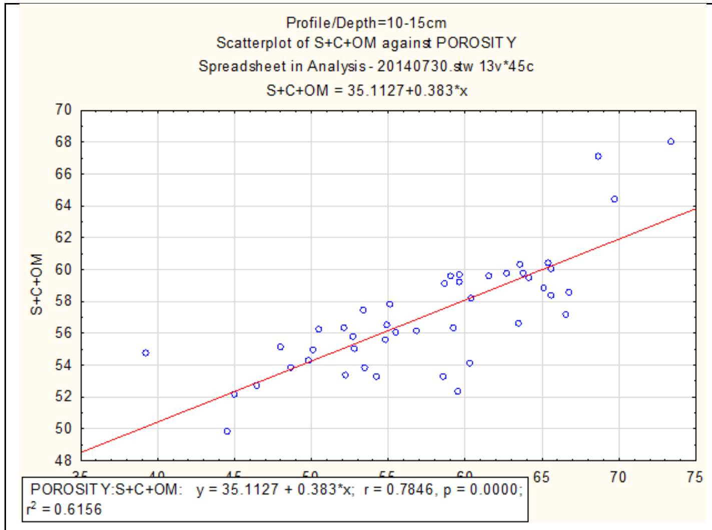


S+C+OM+Z regression correlation with porosity. R^2= 0.5650.

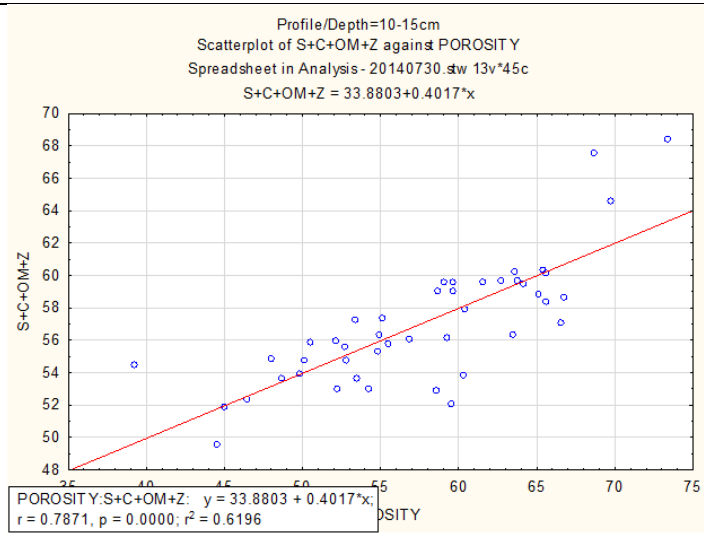


Saxton&Rawls model correlation with porosity. R^2= 0.5666.

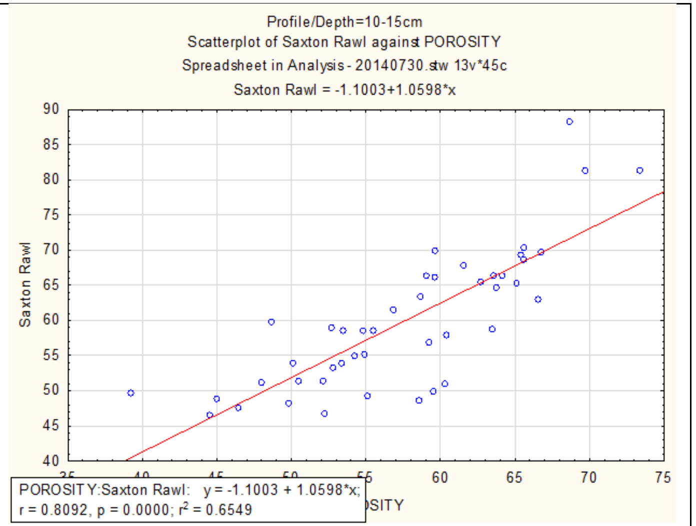
C-3: Correlation of independent variables for the regressions and Saxton&Rawls model in 10-15cm increment.



S+C+OM regression correlation with porosity. R^2= 0.6156.

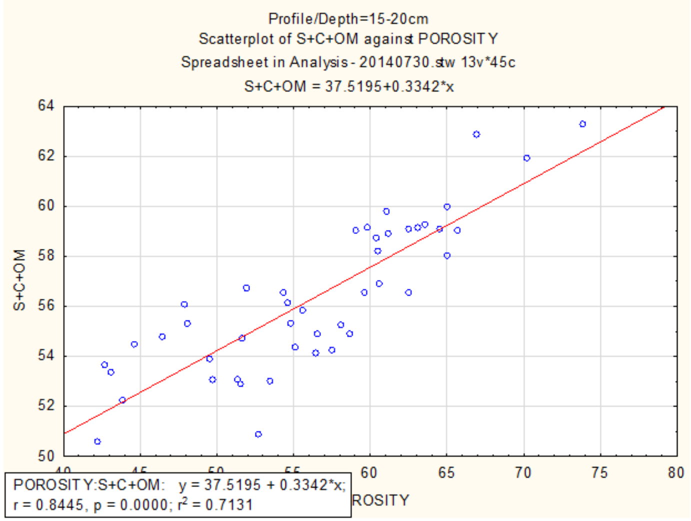


S+C+OM+Z regression correlation with porosity. R^2= 0.6196.

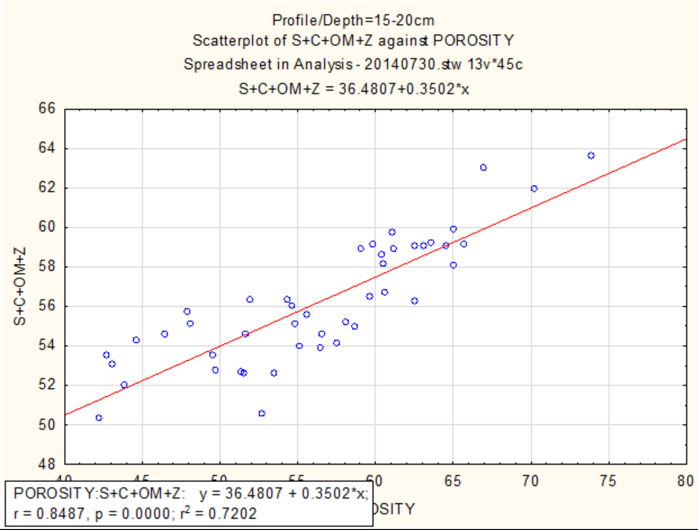


Saxton&Rawls model correlation porosity. R^2= 0.6549.

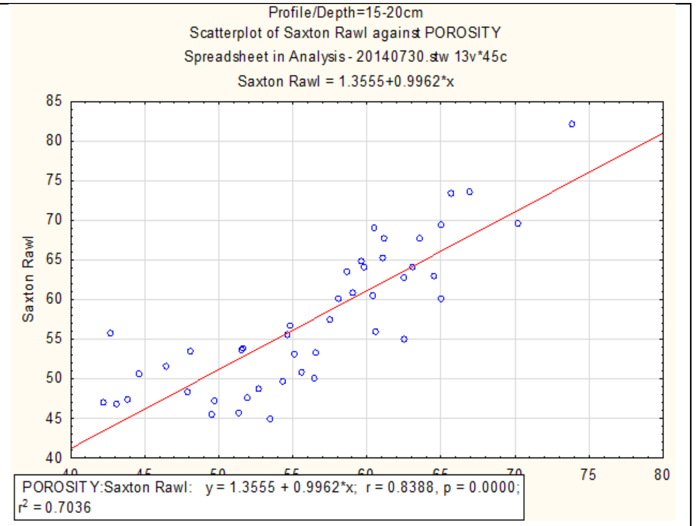
C-4: Correlation of independent variables for the regressions and Saxton&Rawls model in 15-20cm increment.



S+C+OM regression correlation with porosity. R^2= 0.7131.

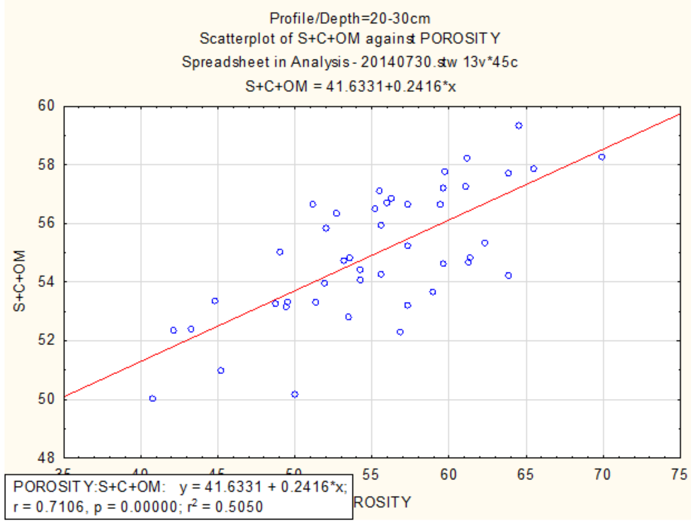


S+C+OM+Z regression correlation with porosity. R^2= 0.7202.

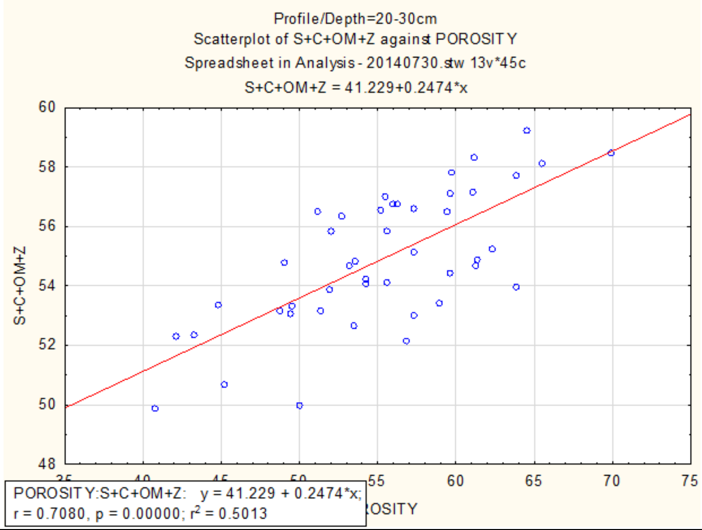


Saxton&Rawls model correlation porosity. R^2= 0.7036.

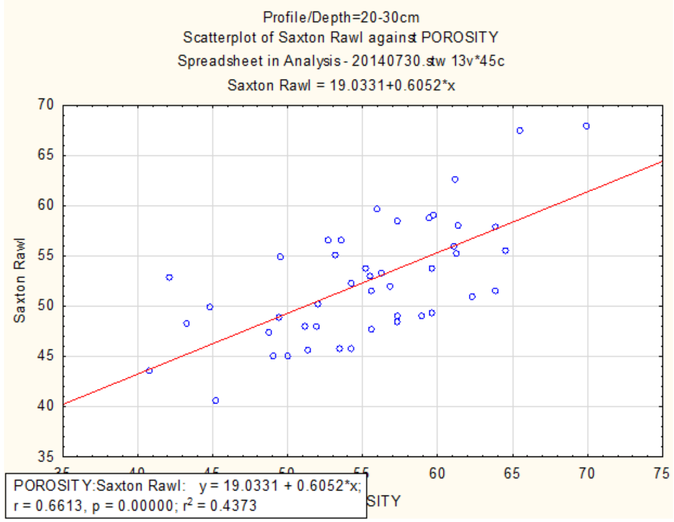
C-5: Correlation of independent variables for the regressions and Saxton&Rawls model in 20-30cm increment.



S+C+OM regression correlation with porosity. R^2= 0.5050.

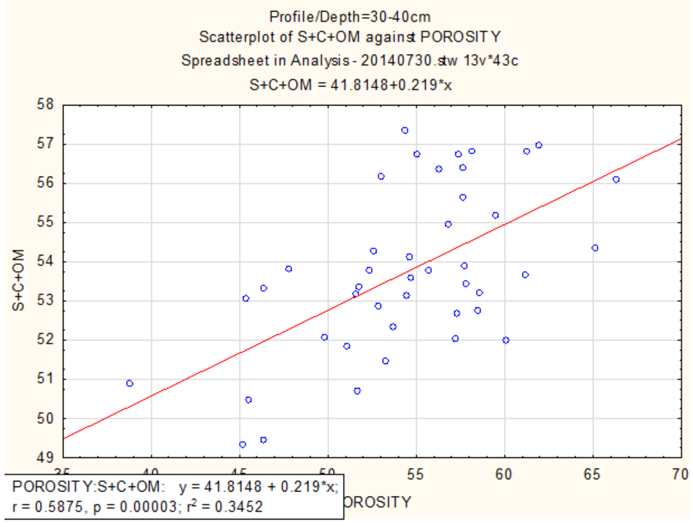


S+C+OM+Z regression correlation with porosity. R^2= 0.5013.

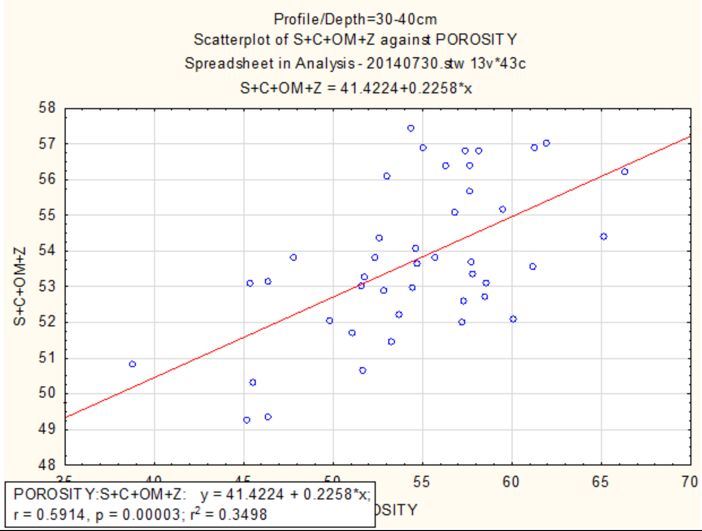


Saxton&Rawls model correlation porosity. R^2= 0.4373.

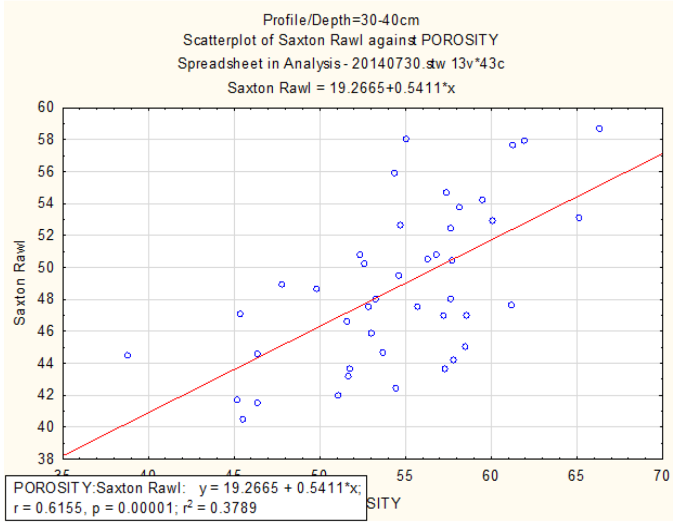
C-6: Correlation of independent variables for the regressions and Saxton&Rawls model in 30-40cm increment.



S+C+OM regression correlation with porosity. R^2= 0.3452.

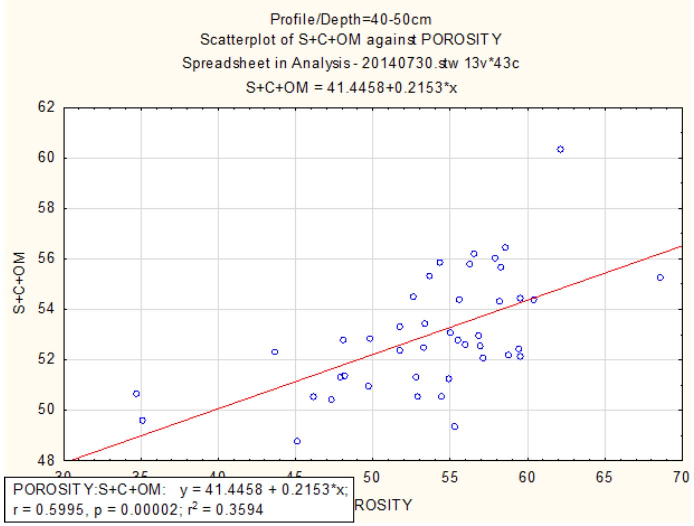


S+C+OM+Z regression correlation with porosity. R^2= 0.3498.

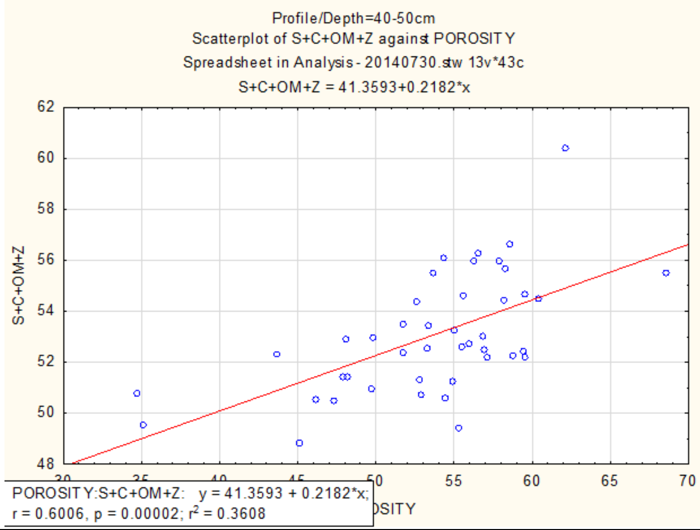


Saxton&Rawls model correlation porosity. R^2= 0.3789.

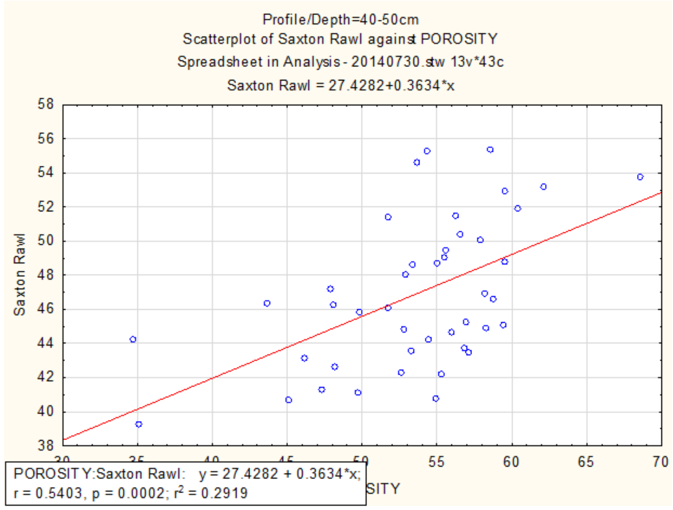
C-7: Correlation of independent variables for the regressions and Saxton&Rawls model in 40-50cm increment.



S+C+OM regression correlation with porosity. R^2= 0.3594.

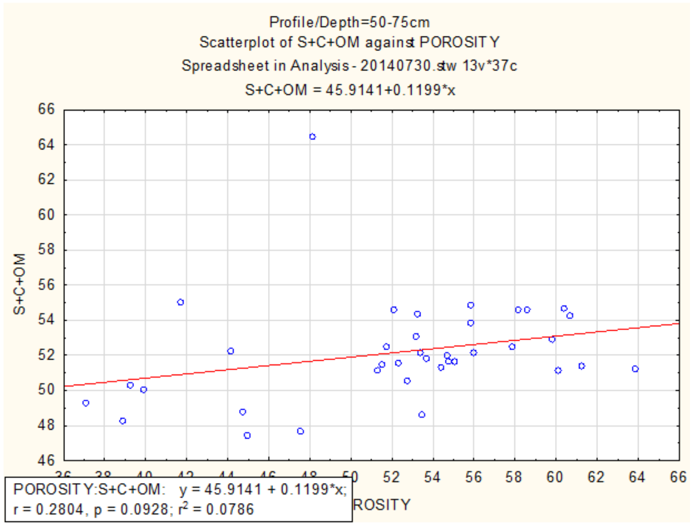


S+C+OM+Z regression correlation with porosity. R^2= 0.3608.

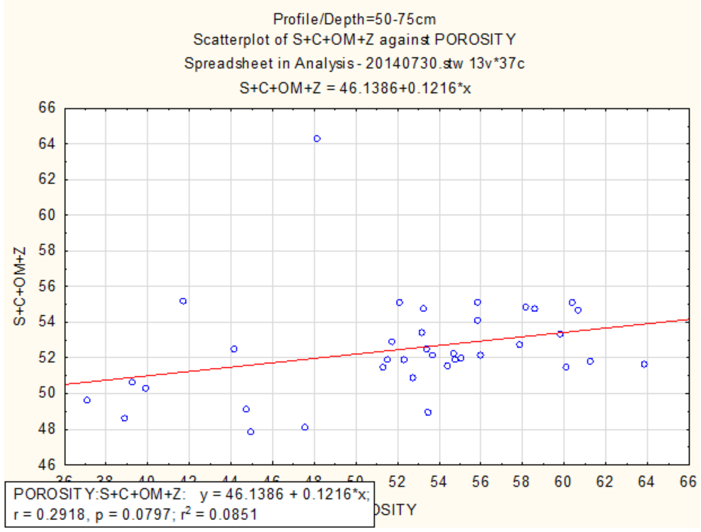


Saxton&Rawls model correlation porosity. R^2= 0.2919.

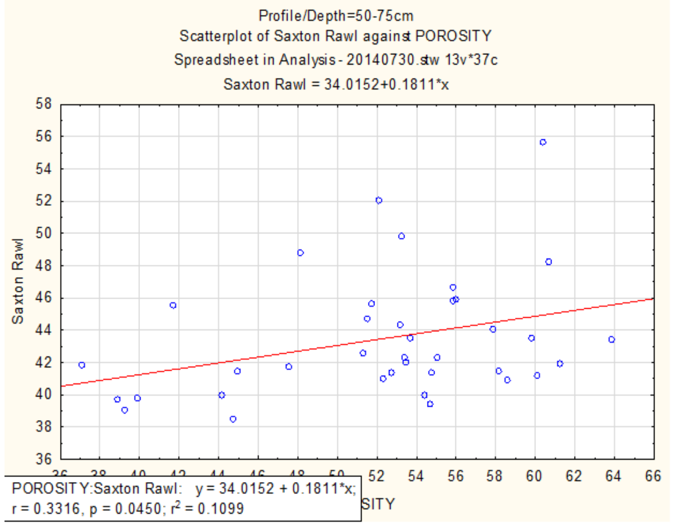
C-8: Correlation of independent variables for the regressions and Saxton&Rawls model in 50-75cm increment.



S+C+OM regression correlation with porosity. R^2= 0.0786.

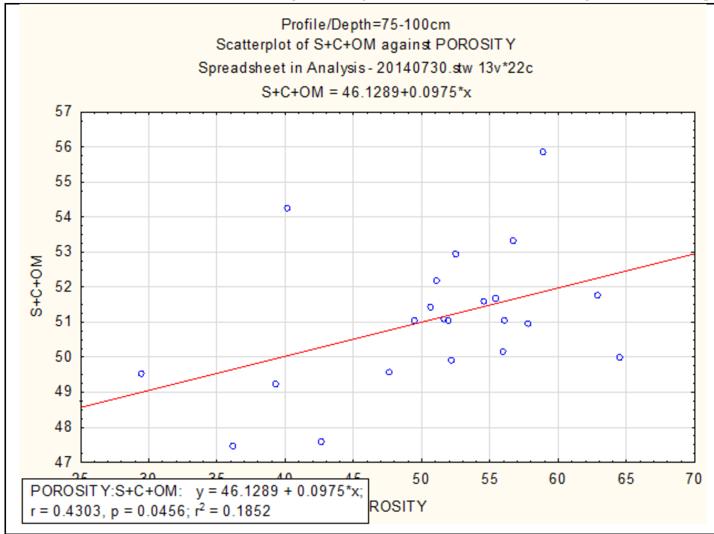


S+C+OM+Z regression correlation with porosity. R^2= 0.0851.

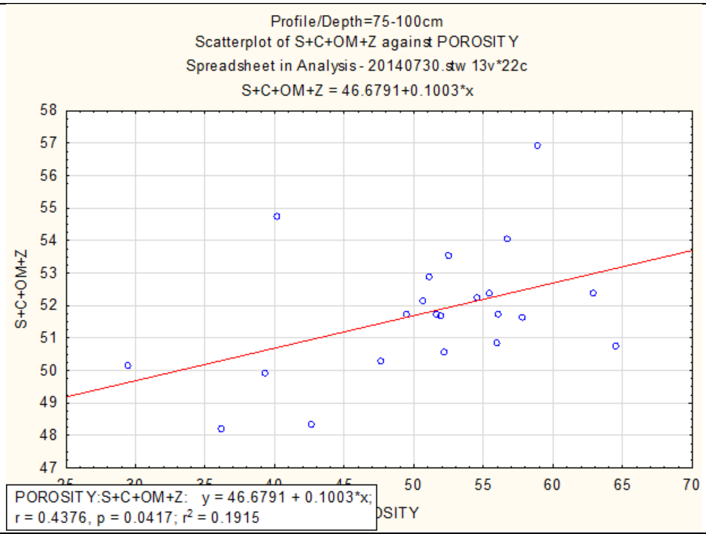


Saxton&Rawls model correlation porosity. R^2= 0.1099.

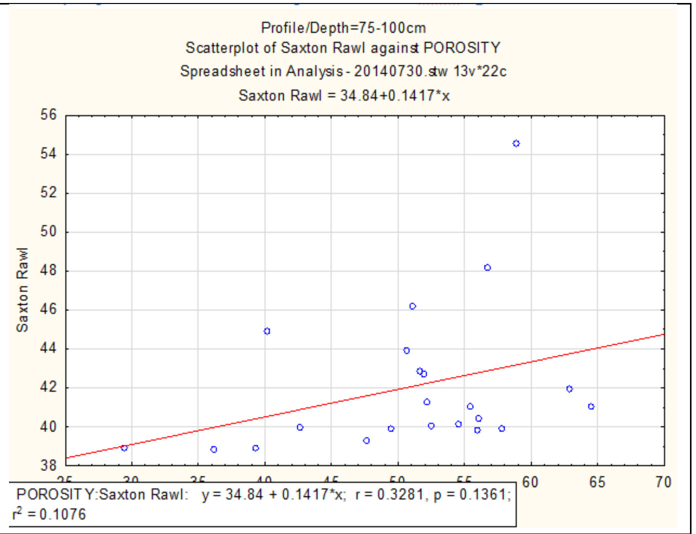
C-9: Correlation of independent variables for the regressions and Saxton&Rawls model in 75-100cm increment.



S+C+OM regression correlation with porosity. R^2= 0.1852.



S+C+OM+Z regression correlation with porosity. R^2= 0.1915.



Saxton&Rawls model correlation porosity. R^2= 0.1076.

ADDENDUM D. BULK DENSITY FOR EVERY LAND USE

1. Grassland

D-1: Saxton&Rawls model bulk density results.

Increment	Profile 8	Profile 10	Profile 12	Profile 16	Profile 36	Profile 37	Profile 42	Average S&R	STD	Std+	Std-
0-5cm	1.326	0.904	1.128	0.465	1.033	0.533	1.033	0.917	0.314	1.231	0.604
5-10cm	1.281	1.071	1.221	0.544	1.150	0.833	1.176	1.039	0.262	1.301	0.778
10-15cm	1.329	1.042	1.321	0.624	1.226	0.947	1.245	1.105	0.255	1.360	0.849
15-20cm	1.367	1.300	1.389	0.581	1.286	0.972	1.253	1.164	0.292	1.456	0.872
20-30cm	1.428		1.483	1.023	1.352	1.246	1.336	1.311	0.163	1.474	1.148
30-40cm	1.468		1.532	1.231	1.512	1.390	1.456	1.432	0.110	1.542	1.322
40-50cm	1.538		1.553	1.279	1.521	1.462	1.485	1.473	0.101	1.574	1.372
50-75cm			1.563	1.586	1.602	1.589	1.467	1.561	0.055	1.616	1.507
75-100cm			1.586				1.529	1.557	0.040	1.598	1.517

D-2: Saxton&Rawls model bulk density results using field bulk density and particle size measured using pycnometer method.

Increment	Profile 8	Profile 10	Profile 12	Profile 16	Profile 36	Profile 37	Profile 42	Average PD	STD	Std+	Std-
0-5cm	1.088	0.702	0.893	0.339	0.881	0.411	0.886	0.743	0.275	1.018	0.467
5-10cm	1.107	0.876	1.015	0.402	1.007	0.659	1.020	0.869	0.252	1.122	0.617
10-15cm	1.192	0.890	1.099	0.493	1.064	0.803	1.095	0.948	0.241	1.189	0.707
15-20cm	1.227	1.179	1.236	0.471	1.175	0.809	1.127	1.032	0.287	1.319	0.745
20-30cm	1.270		1.364	0.848	1.247	1.111	1.195	1.173	0.180	1.352	0.993
30-40cm	1.377		1.466	1.094	1.470	1.247	1.360	1.336	0.144	1.480	1.192
40-50cm	1.477		1.463	1.224	1.478	1.377	1.398	1.403	0.097	1.500	1.305
50-75cm			1.521	1.536	1.541	1.543	1.442	1.517	0.043	1.559	1.474
75-100cm			1.514				1.460	1.487	0.038	1.525	1.449

D-3: Saxton&Rawls model: field bulk density.

Increment	Profile 8	Profile 10	Profile 12	Profile 16	Profile 36	Profile 37	Profile 42	Average CM	STD	Std+	Std-
0-5cm	0.896	0.753	0.742	0.530	0.530	0.666	0.946	0.723	0.163	0.886	0.560
5-10cm	1.147	0.873	0.892	0.581	0.581	0.749	1.097	0.846	0.226	1.072	0.619
10-15cm	1.087	0.813	0.981	0.635	0.635	0.748	1.084	0.855	0.197	1.051	0.658
15-20cm	1.152	1.917	1.026	0.563	0.563	0.771	1.012	1.001	0.465	1.466	0.535
20-30cm	1.017		1.042	0.661	0.661	0.914	1.195	0.915	0.216	1.131	0.699
30-40cm	1.162		1.174	0.794	0.794	0.948	1.242	1.019	0.200	1.220	0.819
40-50cm	1.159		1.178	0.797	0.797	1.177	1.301	1.068	0.216	1.284	0.852
50-75cm			1.256	1.194	1.194	1.350	1.519	1.303	0.137	1.440	1.166
75-100cm			1.224				1.514	1.369	0.205	1.574	1.164

2. Forestry Plantation

D-4: Saxton&Rawls model bulk density results.

Increment	P1	P3	P4	P5	P6	P7	P11	P14	P17	P31	P38	P39	P40	P41	P43	P44	P45	P46	P47	P48	P49	P50	Average S&R	STD	Std+	Std-
0-5cm	0.9	1.1	OOR	0.4	0.4	1.0	0.3	0.3	0.3	1.1	OOR	OOR	0.9	OOR	OOR	0.6	0.6	0.9	0.7	0.2	1.1	0.7	0.7	0.3	1.0	0.4
5-10cm	0.7	1.2	0.5	1.0	1.2	1.3	1.3	1.3	0.6	1.3	1.0	1.1	1.0	0.9	0.9	1.0	0.9	1.3	1.1	0.8	1.2	1.1	1.0	0.2	1.3	0.8
10-15cm	1.0	1.1	1.0	1.1	1.3	1.4	1.3	1.3	0.6	1.3	1.1	1.1	1.1	1.0	1.0	1.1	1.1	1.3	1.2	1.1	1.3	1.2	1.1	0.2	1.3	1.0
15-20cm	0.9	1.2	1.0	1.1	1.3	1.5	1.3	1.3	1.0	1.4	1.2	1.1	1.1	1.0	1.1	1.1	1.1	1.3	1.1	1.2	1.2	1.2	1.2	0.1	1.3	1.0
20-30cm	1.1	1.5	1.2	1.3	1.4	1.5	1.5	1.5	1.3	1.4	1.3	1.3	1.2	1.1	1.3	1.3	1.2	1.3	1.3	1.4	1.4	1.3	1.3	0.1	1.4	1.2
30-40cm	1.5	1.5	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.3	1.3	1.4	1.4	1.3	1.4	1.3	1.3	1.4	1.4	1.4	0.1	1.5	1.3
40-50cm	1.5	1.5	1.5	1.3	1.5	1.6	1.6	1.6	1.5	1.5	1.5	1.4	1.3	1.3	1.6	1.5	1.3	1.4	1.4	1.4	1.4	1.4	1.5	0.1	1.5	1.4
50-75cm			1.5	1.6	1.6		1.5	1.5	1.6			1.5	1.5	1.5		1.6	1.5	1.5	1.4	1.5	1.5	1.5	1.5	0.1	1.6	1.5
75-100cm				1.2	1.6		1.6	1.6									1.5	1.5	1.6				1.5	0.1	1.7	1.4

D-5: Saxton&Rawls model bulk density results using field bulk density.

Increment	P1	P3	P4	P5	P6	P7	P11	P14	P17	P31	P38	P39	P40	P41	P43	P44	P45	P46	P47	P48	P49	P50	Average CM	STD	Std+	Std-
0-5cm	0.6	0.7	0.4	0.7	0.6	0.6	0.5	0.4	0.5	1.0	0.4	0.6	0.7	0.6	0.6	0.7	0.7	0.8	0.9	0.6	0.8	0.8	0.7	0.2	0.8	0.5
5-10cm	0.7	0.8	0.8	0.8	0.9	1.0	0.8	0.5	0.5	1.1	0.8	0.8	0.7	0.8	0.9	0.8	0.6	1.0	0.8	0.7	0.9	1.0	0.8	0.1	1.0	0.7
10-15cm	0.7	0.8	0.8	0.8	1.0	1.0	0.8	0.6	0.5	1.0	0.8	0.8	0.8	0.8	0.8	0.9	0.8	1.0	0.9	0.8	0.9	1.0	0.8	0.1	1.0	0.7
15-20cm	0.7	0.8	0.9	0.9	0.9	1.2	0.9	0.7	0.6	1.0	0.9	0.8	0.9	0.8	0.8	0.9	0.8	1.1	0.9	0.9	0.9	1.0	0.9	0.1	1.0	0.8
20-30cm	0.7	1.0	0.9	0.9	0.9	1.3	1.0	0.8	0.9	1.1	1.0	1.0	0.9	0.9	1.0	1.1	0.9	1.1	1.0	1.1	1.1	1.1	1.0	0.1	1.1	0.9
30-40cm	1.1	1.0	1.0	0.8	1.0	1.3	1.2	0.9		1.1	1.2	1.0	1.0	0.9	1.1	1.3	1.0	1.2	1.0	1.1	1.1	1.1	1.1	0.1	1.2	0.9
40-50cm	1.0	1.0	1.0	1.0	1.0	1.2	1.1	0.9	1.0	1.2	1.3	1.1	0.9	0.9	1.4	1.4	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.1	1.2	1.0
50-75cm			1.1	1.2	1.2		1.1	1.2	1.2			1.1	0.9	1.0		1.2	1.1	1.2	1.1	1.1	1.2	1.2	1.1	0.1	1.2	1.1
75-100cm				1.1	1.2		0.9	1.2									1.1	1.3	1.2				1.1	0.1	1.3	1.0

D-6: Saxton&Rawls model bulk density results using field bulk density and particle size measured using pycnometer method.

Increment	P1	P3	P4	P5	P6	P7	P11	P14	P17	P31	P38	P39	P40	P41	P43	P44	P45	P46	P47	P48	P49	P50	Average PD	STD	Std+	Std-
0-5cm	0.6	0.9	0.4	0.3	0.3	0.6	0.2	0.0	0.2	0.9	OOR	OOR	0.6	OOR	OOR	0.5	0.4	0.7	0.6	0.2	0.9	0.5	0.4	0.3	0.7	0.2
5-10cm	0.6	1.0	0.8	0.8	1.0	1.2	1.0	0.3	0.4	1.2	0.8	0.8	0.8	0.7	0.7	0.8	0.7	1.1	0.9	0.6	1.0	0.9	0.8	0.2	1.1	0.6
10-15cm	0.8	0.9	0.8	1.0	1.1	1.3	1.1	0.3	0.5	1.1	0.9	0.9	0.8	0.8	0.9	0.9	0.9	1.1	1.0	0.9	1.1	1.0	0.9	0.2	1.1	0.7
15-20cm	0.7	1.1	1.1	0.9	1.2	1.4	1.2	0.7	0.8	1.2	0.9	0.9	1.0	0.9	0.9	1.0	1.0	1.1	1.0	1.0	1.0	1.1	1.0	0.2	1.2	0.8
20-30cm	0.9	1.4	1.3	1.2	1.3	1.5	1.3	1.3	1.2	1.3	1.2	1.2	1.1	1.0	1.1	1.2	1.1	1.2	1.1	1.2	1.2	1.2	1.2	0.1	1.3	1.1
30-40cm	1.4	1.4	1.4	1.2	1.4	1.5	1.5	1.2	1.4	1.4	1.3	1.2	1.1	1.1	1.3	1.4	1.2	1.3	1.1	1.2	1.3	1.3	1.3	0.1	1.4	1.2
40-50cm	1.4	1.4	1.4	1.2	1.5	1.5	1.5	1.3	1.4	1.4	1.4	1.3	1.2	1.2	1.5	1.4	1.2	1.3	1.2	1.3	1.3	1.4	1.3	0.1	1.4	1.2
50-75cm				1.5	1.6		1.5	1.5	1.6			1.4	1.2	1.4		1.5	1.3	1.4	1.3	1.4	1.5	1.5	1.4	0.1	1.5	1.3
75-100cm				1.2	1.5		1.5	1.6									1.4	1.5	1.4				1.4	0.1	1.6	1.3

3. Commercial Farming

D-7: Saxton&Rawls model bulk density results.

Increment	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P32	P33	P34	P35	Average S&R	STD	Std+	Std-
0-5cm	1.2	1.1	1.2	1.2	1.1	1.1	1.1	1.2	1.1	1.0	1.2	1.0	0.9	1.3	1.3	1.1	1.1	1.1	0.1	1.2	1.0
5-10cm	1.2	1.1	1.1	1.2	1.3	1.2	1.2	1.2	1.2	1.0	1.2	1.1	1.0	1.3	1.3	1.2	1.1	1.2	0.1	1.3	1.1
10-15cm	1.2	1.2	1.1	1.2	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.3	1.3	1.2	1.1	1.2	0.1	1.3	1.1
15-20cm	1.3	1.1	1.2	1.2	1.3	1.3	1.3	1.2	1.2	1.2	1.3	1.2	1.1	1.3	1.3	1.2	1.1	1.2	0.1	1.3	1.1
20-30cm	1.2	1.3	1.4	1.2	1.2	1.3	1.3	1.2	1.3	1.2	1.2	1.2	1.1	1.3	1.3	1.1	1.2	1.2	0.1	1.3	1.2
30-40cm	1.7		1.9	1.6	1.5	1.7	1.7	1.6	1.7	1.6	1.7	1.5	1.4	1.6	1.6	1.4	1.5	1.6	0.1	1.7	1.5
40-50cm	1.7		1.9	1.7	1.7	1.7	1.7	1.6	1.7	1.6	1.7	1.5	1.5	1.6	1.6	1.6	1.6	1.7	0.1	1.8	1.6
50-75cm	1.9	1.9		1.7	1.8	1.8	1.8	1.7	1.8	1.7	1.8	1.6	1.6	1.7	1.7	1.8	1.5	1.7	0.1	1.8	1.6
75-100cm	1.9			1.9	1.9	1.9	1.9	1.9	1.9	1.9		1.9	1.9	1.9	1.9		1.9	1.9	0.0	1.9	1.9

D-8: Saxton&Rawls model bulk density results using field bulk density and particle size measured using pycnometer method.

Increment	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P32	P33	P34	P35	Average PD	STD	Std+	Std-
0-5cm	1.1	1.0	1.1	1.0	1.0	1.0	0.9	1.0	1.0	0.8	1.1	0.9	0.8	1.2	1.2	1.1	1.0	1.0	0.1	1.1	0.9
5-10cm	1.1	1.0	1.0	1.0	1.2	1.2	1.1	1.0	1.1	0.9	1.1	1.0	0.9	1.2	1.2	1.0	1.0	1.1	0.1	1.2	1.0
10-15cm	1.1	1.0	1.0	1.0	1.2	1.2	1.1	1.1	1.1	1.0	1.1	1.0	0.9	1.2	1.1	1.1	1.0	1.1	0.1	1.2	1.0
15-20cm	1.1	1.0	1.0	1.0	1.2	1.2	1.2	1.2	1.1	1.1	1.2	1.1	0.9	1.2	1.2	1.1	1.0	1.1	0.1	1.2	1.0
20-30cm	1.1	1.2	1.3	1.0	1.1	1.3	1.2	1.2	1.3	1.2	1.2	1.1	1.0	1.2	1.2	1.0	1.1	1.2	0.1	1.2	1.1
30-40cm	1.5		1.9	1.4	1.5	1.7	1.6	1.5	1.6	1.5	1.6	1.4	1.4	1.6	1.6	1.3	1.4	1.5	0.1	1.7	1.4
40-50cm	1.6		1.9	1.3	1.8	1.7	1.6	1.5	1.6	1.5	1.6	1.4	1.3	1.5	1.6	1.4	1.5	1.6	0.2	1.7	1.4
50-75cm	1.8	1.8		1.8	1.8	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.6	1.7	1.7	1.9	1.4	1.7	0.1	1.8	1.6
75-100cm	1.9			1.8	1.9	1.8	1.8	1.8	1.9	2.0		1.8	1.8	1.8	1.9		2.0	1.9	0.1	1.9	1.8

D-9: Saxton&Rawls model bulk density results using field bulk density.

Increment	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P32	P33	P34	P35	Average CM	STD	Std+	Std-
0-5cm	1.0	1.1	1.2	1.0	1.1	1.1	1.1	0.8	1.0	0.9	1.1	1.1	1.1	1.0	1.0	1.1	1.1	1.0	0.1	1.1	1.0
5-10cm	1.1	1.2	1.1	1.2	1.4	1.4	1.2	1.0	1.2	1.0	1.4	1.0	1.1	1.0	1.1	1.0	1.1	1.1	0.1	1.3	1.0
10-15cm	1.0	1.2	1.1	1.4	1.4	1.4	1.2	1.1	1.2	1.1	1.3	1.1	1.1	1.1	1.1	1.0	1.2	1.2	0.1	1.3	1.0
15-20cm	1.3	1.2	1.2	1.3	1.3	1.5	1.2	1.2	1.3	1.1	1.4	1.1	1.1	1.2	1.1	1.0	1.2	1.2	0.1	1.3	1.1
20-30cm	1.2	1.3	1.3	1.0	1.4	1.5	1.2	1.2	1.3	1.1	1.4	1.1	1.1	1.1	1.2	1.1	1.2	1.2	0.1	1.4	1.1
30-40cm	1.1	1.4	1.5	1.0	1.4	1.4	1.2	1.2	1.3	1.0	1.2	1.0	1.1	1.2	1.1	1.1	1.1	1.2	0.1	1.4	1.1
40-50cm	1.3	1.2	1.7	1.0	1.4	1.4	1.1	1.0	1.2	1.1	1.3	1.0	1.1	1.1	1.1	1.2	1.1	1.2	0.2	1.4	1.0
50-75cm	1.2	1.5		1.5	1.5	1.6	1.2	1.1	1.2	1.2	1.6	1.0	0.9	1.0	1.0	1.6	1.3	1.3	0.2	1.5	1.0
75-100cm	1.3			1.5	1.6	1.6	1.3	1.2	1.2	1.2		1.2	0.9	1.1	1.1		2.0	1.3	0.3	1.6	1.0

ADDENDUM E. STATISTICS SUPPORTING THE USE OF LAND USE AS A MAIN FACTOR OF THE MODEL

D.1 All Groups: Descriptive Statistics

	All Groups Descriptive Statistics (Data in Analysis - 20140903.stw)											
Variable	Valid N	Mean	Confidence -95.000%	Confidence 95.000%	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Percentile 10.00000	Percentile 90.00000	Std.Dev.
Actual	46	15.19508	13.88459	16.50556	14.97706	6.9131	26.11504	11.88011	18.40774	9.81381	21.25361	4.412949
Predicted	46	14.67940	12.88544	16.47336	13.56212	5.1678	34.25439	10.77421	18.46729	8.41609	22.18560	6.041008
Difference: Actual - Predicted	46	0.51568	-0.39355	1.42490	0.96916	-14.6110	4.80838	-0.30379	2.38424	-2.99677	2.84746	3.061751

D.2 Land Use=Forestry: Descriptive Statistics

	Land Use=Forestry Descriptive Statistics (Spreadsheet in Analysis - 20140903.stw)											
Variable	Valid N	Mean	Confidence -95.000%	Confidence 95.000%	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Percentile 10.00000	Percentile 90.00000	Std.Dev.
Actual	22	17.14499	15.07612	19.21387	17.73259	6.9131	26.11504	14.12222	19.87137	10.98217	21.28331	4.666199
Predicted	22	18.07176	15.22302	20.92049	17.49170	6.6567	34.25439	14.36942	21.55702	9.41345	25.82836	6.425119
Difference: Actual - Predicted	22	-0.92676	-2.54004	0.68652	0.09841	-14.6110	2.64318	-1.65050	1.11597	-3.82456	1.89508	3.638631

D.3 Land Use=Farmland: Descriptive Statistics

	Land Use=Farmland Descriptive Statistics (Spreadsheet in Analysis - 20140903.stw)											
Variable	Valid N	Mean	Confidence -95.000%	Confidence 95.000%	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Percentile 10.00000	Percentile 90.00000	Std.Dev.
Actual	17	13.40541	11.62503	15.18579	12.98543	7.86218	21.37591	11.42232	14.40215	9.475025	19.76419	3.462751
Predicted	17	11.43754	9.60803	13.26704	10.96074	5.16778	18.88784	8.78745	13.03624	8.416093	18.85453	3.558298
Difference: Actual - Predicted	17	1.96788	1.14889	2.78686	2.38424	-1.29179	4.80838	0.71905	2.70450	-0.558491	3.89230	1.592879

D.4 Land Use=Grassland: Descriptive Statistics

	Land Use=Grassland Descriptive Statistics (Spreadsheet in Analysis - 20140903.stw)											
Variable	Valid N	Mean	Confidence -95.000%	Confidence 95.000%	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Percentile 10.00000	Percentile 90.00000	Std.Dev.
Actual	7	13.41309	10.32447	16.50170	15.57059	8.361712	16.34882	9.813810	16.16498	8.361712	16.34882	3.339599
Predicted	7	11.89081	8.38056	15.40105	11.98467	5.685910	16.73744	8.308827	14.44610	5.685910	16.73744	3.795493
Difference: Actual - Predicted	7	1.52228	0.08464	2.95992	1.42731	-0.388620	4.18031	-0.020881	2.67580	-0.388620	4.18031	1.554461